Development of An Integrative Water Quality Monitoring Programme for Te Waihora/Lake Ellesmere

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by

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Fresh water lakes are highly valued in today's world. The use and management of this freshwater resource is critical to all four well-beings (social, economic, environmental, and cultural) worldwide and specifically (for this thesis), in Canterbury, New Zealand. Lake Ellesmere/Te Waihora is a coastal ICOLL (Intermittently Closed and Open Lake or Lagoon) where the effects of the local climate patterns, the use and management of the large catchment associated with this lowland lake, its numerous stakeholders and changing legislation, have created a situation where robust relevant data is essential to ensure best and most cost-effective management of this resource. New Zealand legislation acknowledges the importance of this ICOLL within the whole system of New Zealand lakes, and views it as an indicator of New Zealand ICOLL behaviour.

Water quality is an important facet of freshwater management and is one aspect of an overarching monitoring strategy for Te Waihora developed in 2015. Water quality monitoring in the lake is carried out by the regulatory body as well as many other stakeholders. This has led to an abundance of data addressing very specific objectives but also a number of gaps in the data required to assess the overall state of Te Waihora itself. The purpose of this research is to design a water quality monitoring programme integrating and augmenting existing programmes which will cost-effectively add to the information required for stakeholders and support current and future management.

This research initially compiled information pertaining to lake character, the effects of land use within the large catchment and the local climatic conditions relevant to the lake, as well as existing monitoring programmes. An 'ideal' water quality monitoring programme with the main objective being "to assess the state and trends of water quality in Te Waihora and its immediate catchment" was then designed using specific predetermined criteria to select tributaries, monitoring sites, parameters and monitoring frequency. Current legislation and the importance of the local conditions for targeted monitoring to be achieved were incorporated and further information needs identified.

The proposed monitoring programme requires monthly monitoring of six lake and eight tributary sites. The NPS-FM 2014 (amended 2017) and CLWRP water quality parameters, as well as parameters specific to Te Waihora are taken account of. These include monthly lake attributes (parameters) of lake level, pH, temperature, electrical conductivity, DO, turbidity, TSS, VSS, Secchi Disc, NO_2-N, NO_3-N, NH_4-N, TN, DRP, TP, chl *a* and *E. Coli* and monthly tributary attributes (parameters) of discharge, pH, temperature, conductivity, DO, clarity, turbidity, TSS, NO_2-N, NO_3-N, NH4-N, TN, DRP, TP and *E. Coli*, with yearly monitoring for Cu, Pb, Zn, Cd, selected emerging contaminants and polyaromatic hydrocarbons (PAH). Additional monitoring is proposed for further specific parameters (e.g., flood and flow loads) at predetermined events (e.g., when tributary flow reaches a predetermined level). Tributary flow, lake level, climatic conditions and ICOLL status (open or closed) should also be recorded.

This designed water quality monitoring programme has been compared with existing stakeholder monitoring programmes, to identify gaps and omissions and recommend methods for these to be addressed. Additional recommendations for methods to achieve the overarching integrative water quality monitoring objectives for foreseeable future requirements for management and modelling are also made. The 'robustness' and quality control of all aspects of the monitoring (practical and financial) is acknowledged as essential for longevity.

Additional research into key areas, such as the sediment load related to flooding events, the combination of more extreme intermittent climatic conditions with increased intensification of catchment use, the effect of the Central Plains Water Ltd (CPWL) irrigation scheme and the effect of openings and closings on Te Waihora, are recommended to aid management decisions, aimed at not only sustaining the environment of the lake, but regenerating and improving it.

Keywords: water quality, freshwater monitoring, freshwater lakes, Te Waihora, Lake Ellesmere, ICOLL, integrative, stakeholders, robust.

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Chapter One – Introduction

1.1 Freshwater lakes and their value in today's world

Fresh water is our most precious resource, as it is essential for the survival of all living things (Gleick, 1993). Three out of four jobs worldwide are water dependent (UNWWAP, 2016) with modern society as well as developing countries requiring a plentiful supply of fresh water (Tchobanoglous & Schroeder, 1987). This is reiterated in New Zealand where the country's small open economy is underpinned by the products of natural resources (OECD, 2017). Falkenmark (1997) emphasised the necessity of water for all facets of life, not only its growing scarcity associated with food production and industrial and commercial development, but as an integral part of ecosystems worldwide. However, the biota of many freshwater habitats is being destroyed faster than it can be protected or studied (Gleick, 1993).

The multiple stressors on this available fresh water such as an increasing population, urbanization, imprudent land use intensification and a variety of contaminants are threatening worldwide aquatic systems and causing increasingly negative impacts (Strobl & Robillard, 2007). This competition for the use of freshwater is higher in regions where rainfall is low (for example, Canterbury, New Zealand). The world's water resource planners have been predicting that anthropogenic use of global water resources will lead to a world water crisis due to management rather than availability (Brichieri-Colombi, 2009). Natural lakes and their associated waterways and wetlands play an important role within this freshwater system.

The value of natural lakes can be seen in Figure 1-1, which shows the percentage of the world's available fresh water (WBCSD, 2005). Lakes have immense intrinsic value as natural features, ecosystems and biota. The increased interest in, and management of, these lakes and their catchment areas have a high priority in new freshwater legislation (Harding et al., 2004).

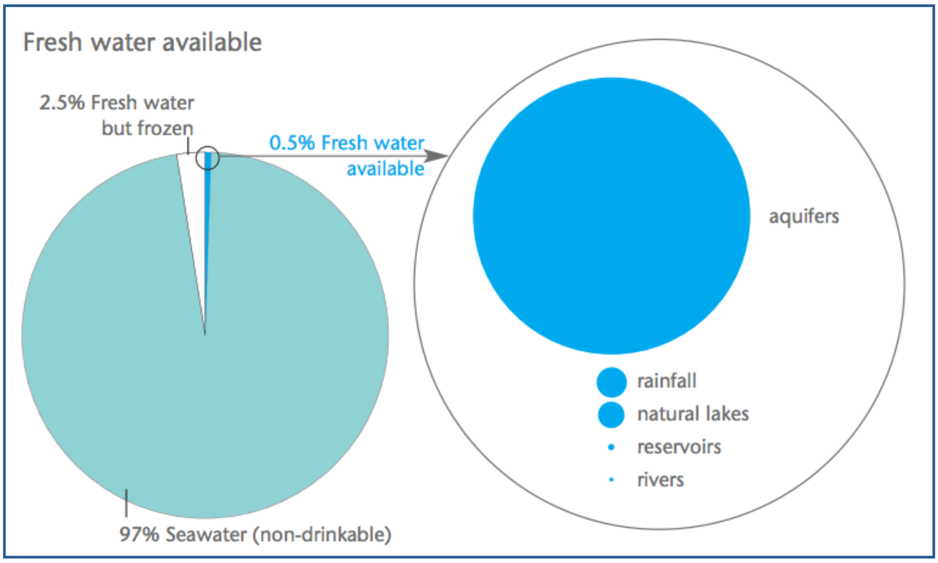

Figure 1-1: Available fresh water (WBCSD, 2005).

1.2 Freshwater management

The recognition of the importance of worldwide freshwater management led to the establishment in 2003 of UN-Water, a UNESCO inter-agency organization for all freshwater-related issues. An annual report is produced on behalf of UN-Water showing the global strategic outlook on the state of freshwater resources, regional assessments, resource based trends in the various sectors and management options (WWAP, 2017).

One of the main problems of the UNEP (sustainable use of water) can equitably be solved by an integrative management approach to the use of water (UNEP, 2012). Unprecedented economies of scale in the globalization of trade and markets in the world economy, is leading to new financial and marketing structures which are accelerating environmental degradation (and the awareness of this degradation), confirming this requirement for integrative monitoring and management of water resources on a worldwide, as well as local scale (Kumagai & Vincent, 2003; WBCSD, 2005). This problem of integrated freshwater management has long been recognized, as outlined by Ward, Loftis & McBride (1986), where water quality monitoring is described as often being data-rich but information-poor (due to the omission of *why* from *who, what, where* and *when*).

The eutrophication of lakes is a major issue for freshwater management as outlined by Elliott & Sorrell (2002). The OECD addresses this eutrophication and its management using the concept of Pressure, State, Response (PSR); see Figure 1-2 (Hughey et al., 2004). This is based on the concept that natural and anthropogenic activities exert a pressure on the environment, thus changing the state of the environment (e.g., water quality and quantity). This initiates a response to these changes (the impact the change has created; Boothroyd & Drury, 2003). This model is said to give a measure of the sustainability of the system and its management. The PSR structure is a means of quantifying environmental pressures and is used in freshwater management to measure change and the impact of policies and programmes.

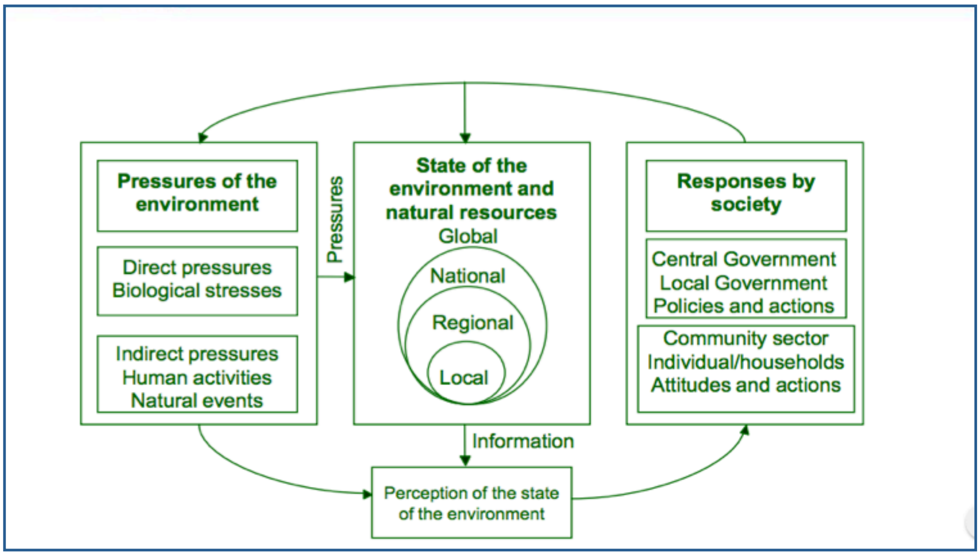

Figure 1-2: Pressure State Response Framework for Environmental Reporting (Hughey et al., 2004).

The Australian Government uses an adaptive management and accountability system to address its natural resources management, using the objectives set out in 'Sustainable Environment Stream Monitoring, Evaluation, Reporting and Improvement (MERI) Plan'. This plan details key performance indicators (KPIs) and key evaluation principles (KEPs). This system underpins the reporting of the data, which additionally shows outcomes and progress (Australian Government, 2013). Hughey et al. (2013) advocates the integration of this system with the current management systems already operating in New Zealand.

1.2.1 Freshwater management in New Zealand

In New Zealand, "our freshwater environments support our way of life"; that is, water sustains our agriculture, industries, tourism, and the health and well-being of people and communities (MfE, 2014). For Māori, fresh water is a taonga (treasure; MfE, 2014a). The international perception of New Zealand as being clean and green plays a major role in the country's economy and, in 2003, New Zealand ranked in the top ten for freshwater cleanliness and abundance, but to achieve good management of our freshwater systems in the future, we must understand how these systems and the water users function (Woods & Howard-Williams, 2004). Good science, data, and information are required to ensure we manage and transform any impact we have, to support our growing population and increase our economy, based on primary industries (MfE, 2014a), but New Zealand's growth model is approaching its environmental limits (OECD, 2017). Figure 1-3 below, shows New Zealand has the highest per capita use of freshwater for agriculture in the OECD.

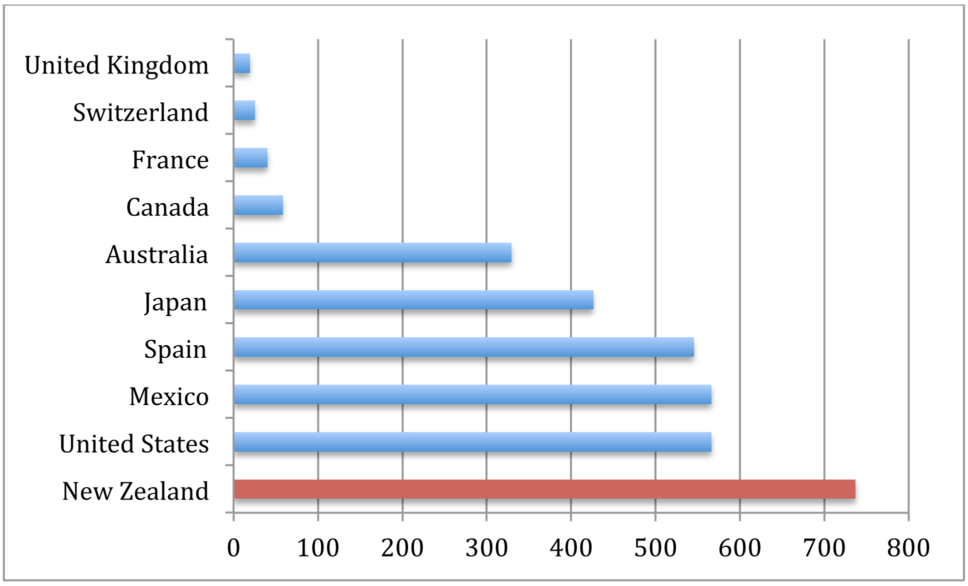

Figure 1-3: Freshwater abstraction for agriculture (m^3/person/yr (2014); OECD, 2017).

Responsibility for freshwater management in New Zealand began to change in the 1980s when regional councils were created (based on major catchment boundaries, Figure 1-4) and their responsibilities outlined under the environmental legislation of the Resource Management Act 1991 (RMA). This document outlines how we manage our environment—the responsibilities of national and local government, the processes involved in resource consents, regional and unitary plans, planning, monitoring and reporting. This legislation has the intent of sustainable resource management. It is "effects-based" focusing on the results of activities rather than on the complete ecosystem. However, despite the implementation of the RMA, in 2007 an ongoing decline in freshwater quality was identified.

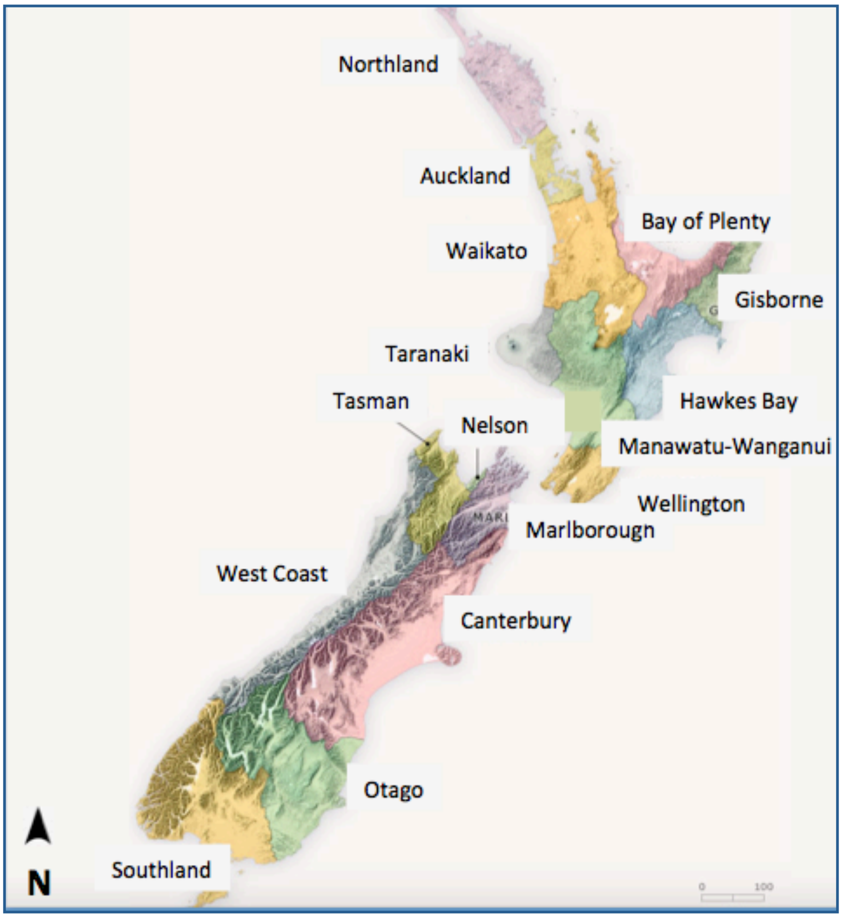

Figure 1-4: Regional council boundaries in New Zealand.

In 2009, the key users and stakeholders in land and water were invited to join a "Land and Water Forum" (LWF) advisory group comprising local iwi, environmental and recreational nongovernmental organizations, industry groups, regulators and other freshwater stakeholders, with the objective of collaboratively developing a shared vision and more effective ways to improve water management. This forum makes recommendations to government through the Ministers for the Environment and for Primary Industries. Their first report culminated in formulating the National Policy

Statement for Freshwater Management (NPS-FM) to provide direction to regional and local government (MfE, 2014a). The report incorporates the National Objectives Framework (NOF) where objectives and limits are set for water bodies. Further reports to government have led to additional recommendations and further modification of the NPS-FM legislation. Integrated catchment management systems (with robust limits) are recognized in the Fourth Report of the LWF, to be an essential part of the legislation (LWF, 2015a). Other historic, as well as more current legislation, standards and regulations support the RMA (MfE, 2014a), such as the National Environmental Standard for Sources of Human Drinking Water (Ministry of Health, 2008), and Water Conservation Orders. Environmental management in New Zealand is reported on in the biennial State of the Environment Report.

This freshwater management reform has been ongoing since 2007, but the results of the "form" it takes have changed over time. The traditional approach for overall water management has been what can be known as the "hard path". It was established when centralized infrastructure, large dams or reservoirs, pipelines and treatment plants were the major part of water management (Wolff & Gleick, 2004). In more recent times and due to the very litigious system that evolved following the establishment of the RMA, another path has emerged; the "soft path" for water management. This new approach has a slightly different set of goals involving a more collaborative approach to the delivery of water-related services matching user needs (including the environment) and resource availability (Wolff & Gleick, 2004).

Freshwater management reform in New Zealand is incorporating this collaborative aspect, involving all river, lake and catchment stakeholders in catchment decisions. In Canterbury, this led to the Canterbury Water Management Strategy (CWMS) initiated by the Canterbury Mayoral Forum. It is a partnership between the Canterbury Regional Council (Environment Canterbury; ECan), Canterbury's city and district councils, Ngāi Tahu (the principal Māori iwi of the southern region of New Zealand) and water stakeholders. This strategy involved extensive collaborative processes and included sustainably progressing the four well-beings (RMA target areas of environment, economic, social and cultural; ECan, 2009a). The values of kaitiakitanga (guardianship and protection), ecosystem health, drinking water, commercial, recreational and amenity opportunities were incorporated in all discussions (MfE, 2014b; MfE, 2016a). Local zone committees were established to collaboratively address parochial water issues. These are advisory committees to council and provide advice through their Zone Implementation Programmes (ZIP) and ZIP Addendums on the local priorities to be incorporated into the Land and Water Regional Plan. The Selwyn-Te Waihora zone committee was one of the first to carry out these new initiatives.

Figure 1-5 shows the recent timeline of reforms. The fresh water 2017 report is the first report in New Zealand's Environmental Reporting Series dealing solely with fresh water (MfE, 2017a). A key message from this report is the need to improve data collection and reporting on fresh water, specific to national and local environments.

Freshwater Reform Timeline

2009

- Land and Water Forum established to advise on water reform
- Land, Air, Water Aotearoa (LAWA) website launched

2010

- Resource Management (measurement and reporting of water takes) Regulations introduced

2011

- National Policy Statement for Freshwater Management introduced
- Fresh Start for Freshwater clean-up
- Irrigation Acceleration Fund established

2013

- Consultation on Freshwater Reform 2013 and Beyond

2014

- National Policy Statement for Freshwater Management amendments introduce National Objectives Framework and National Bottom Lines for water quality
- Te Mana O Te Wāi Fund established

2015

- Environmental Reporting Act passed
- Environment Aotearoa released

2016

- Consultation on proposed changes to the National Policy Statement for Freshwater Management (Next Steps for Fresh Water)
- Our Land and Water Science Challenge launched

2017

- Consultation on Clean Water
- Targets for freshwater quality for swimming proposed
- Swimming maps launched
- Freshwater Improvement Fund established
- Regulations for stock exclusion from waterways proposed

Figure 1-5: Freshwater reform in New Zealand timeline (MfE, 2017a).

1.2.2 Water quality management in New Zealand

Water quality management in New Zealand was historically undertaken according to the original regulations of the RMA (section 43). The *state* of a water body was graded according to ANZECC (2000) (The Australian and New Zealand Guidelines for Fresh and Marine Water Quality). However, within the Environmental Reporting Act 2015, the regulations were adapted to encompass a much larger view of the whole environmental ecosystem. There are five *domains* of which fresh water is one and the Environment Aotearoa Report (MfE, 2015) expands on the change from a "snap-shot" approach to the PSR system (which is designed to detect changes in state in relationship to pressure). The disadvantages of the PSR system are that the significance of natural processes is minimised, and it assumes cause and effect (Boothroyd & Drury, 2003). The Environmental Reporting Regulations (2016) set out the *topics* to be reported on. These topics identify the key areas of interest and are intended to ensure consistency and continuity of information over time.

As previously stated, the NPS-FM (2014) is the directive for freshwater management for local, regional and national values. This policy statement and the NOF underpin the freshwater plans and objectives for the local communities. They also emphasise the place of the Treaty of Waitangi as the underlying foundation of the Crown-iwi/hapū relationship for fresh water. The NPS-FM (2014) sets out bottom lines for ecosystem health and human health for recreation. These bottom lines are not standards and where they are not achieved, plans for improvement must be in place. The NPS-FM (2014) states that monitoring plans are to be practical and affordable (MfE, 2014a). Objective A (water quality) and objective B (water quantity) state that climate change, the connection between water bodies and the connection between freshwater bodies and coastal water, should be taken into account. Objective C (integrated management) requires management to integrate all aspects between fresh water, land use, associated ecosystems and the coastal environment. All three objectives must be consistent with national and regional objectives but at the same time, relevant on a local level (NOF Policy CA1). NOF Policy CB1 states that monitoring sites must be representative and show long-term trends.

Appendix 2 Attribute Tables of the NPS-FM (2014) require the following parameters to be monitored (MfE, 2014a):

- Lakes: chlorophyll *a* (chl *a*), total nitrogen (TN), total phosphorus (TP), for ecosystem health.
- Rivers: chlorophyll *a* (chl *a*), nitrate nitrogen (NO_3-N), ammoniacal nitrogen (NH_4-N), dissolved oxygen (DO), for ecosystem health.

The NZ government freshwater reform programme continues to update the requirements and recommendations for water quality monitoring. An example is where an amendment for water quality (3.4 Managing nitrogen and phosphorus) to the NPS-FM (2014) in the report *Clean Water, 2017* is for dissolved inorganic nitrogen (DIN) and dissolved reactive phosphorus (DRP) to be measured routinely.

Item 3.7 (*Coastal lakes and lagoons*) has been an area of confusion, but is clarified in this most recent discussion document *Clean Water* (MfE, 2017b) that ICOLLs have the same attributes as freshwater lakes (MfE, 2016c). This *Clean Water, 2017* document notes future areas for consideration (and monitoring) in the urban and rural sector (MfE, 2017b).

A National Monitoring System (MfE, 2017a) has recently been designed, developed and implemented, but will be regularly updated and improved. Compliance, monitoring and enforcement are the responsibility of both regional councils and territorial authorities (district and city councils). There is a significant variation in the way different councils carry out compliance, monitoring and enforcement. There is allowance in the RMA for a graduated level of compliance and enforcement (MfE, 2016d). The cost to enforce compliance is a necessary aspect to be considered. Most councils use a “risk-based” approach to monitoring, and most regulatory specialists now argue, on the basis of considerable evidence, that a judicious mix of compliance promotion and deterrence is likely to be the best enforcement strategy (MfE, 2016d). The traditional “carrot and stick” situation still applies, but a more collaborative system has been introduced to acheive improvement in stakeholder communications and actions (ECan, 2011).

New Zealand’s progress towards the environmental policy objectives and their progress towards green growth and sustainable development is reported on by the OECD

Environmental Performance Reviews (EPRs). They provide evidence-based analysis and assessment to enhance government accountability and provide targeted recommendations. Their focus is on water resource management as well as sustainable urban development. Since 1973 when New Zealand joined the OECD, three reviews have been published—in 1996, 2007, and 2016 (OECD, 2017). The Water Resources Management report of the OECD 2016 notes the growing environmental and public concern of the cumulative effect of pastoral intensification and urban storm-water run-off on freshwater quality and quantity (MfE, 2016b). This report, along with the growing public interest and concern about the water quality and the environment, leads to the increasing importance of management and monitoring of fresh water.

1.2.3 The importance of monitoring in freshwater management

The importance of monitoring for management is emphasised by Telci et al. (2009) who stated that water quality monitoring should provide robust and timely information to enable sustainable management of all aspects of the freshwater system. Additionally, the OECD (2017) report states that the competing needs of stakeholders (environment, land use, and healthy ecosystems) for fresh water are an emerging and urgent concern and will be exacerbated by climate change.

Monitoring is the consistent, regular, long-term gathering of data, which may include water chemistry, hydrology, particulate material, or aquatic biota. Traditionally the assessment of water quality was to establish suitability for its intended use—usually a single purpose such as swimming. However, monitoring now typically involves determining trends in the aquatic environment, levels of contamination, fluxes and their effects, and the detection of the effects of anthropogenic activities. Trend, “fit-for-purpose” and/or impact monitoring, may be required, resulting in today’s water quality monitoring programmes having multiple objectives. Management and restoration information rely on water quality monitoring programme data. Land use management plans and limits cannot be set if monitoring has not been carried out (LWF, 2015b). Although the RMA is very comprehensive, its full potential for establishing environmental rules for monitoring and managing water quality has not been adequately reached and some significant gaps are still evident (OECD, 2017).

The Selwyn–Waihora Zone Implementation Programme (ZIP) is an example where water quality monitoring is an essential requirement for most of the recommendations of the CWMS targets (ECan, 2011), but Hughey et al. (2004) state that, in order for the management to be effective and sets of water quality indicators consistently monitored and reported, there should be a strong relationship between the results and the management's actions. The Fourth Report of the Land and Water Forum states that "Better science and information will allow communities and land and water users to identify and implement the optimal suite of mitigations over time" (LWF, 2015a). The purpose of a water quality monitoring programme is to provide a tool to capture the cause and effect of all activities/stressors in a waterbody system.

1.3 Design of water quality monitoring programmes

There has been a steady evolution in procedures for designing monitoring programmes to obtain information in specific environments. Multiple stressors in freshwater ecosystems (0merod et al., 2010) emphasise the extent to which new challenges are emerging and the need to capture and monitor cumulative effects. Present-day water quality monitoring programmes need to incorporate the multiple objectives in the spatial and temporal selection of parameters, and chosen monitoring sites. A holistic appraisal of the monitoring objectives, site locations, sampling frequencies and parameters is necessary (Strobl & Robillard, 2007). However, the simple *why-what-where-when-how*, continues to be the base of any water quality monitoring programme.

The underlying concepts of a water quality monitoring programme design are given in *Water Quality Assessments - A Guide to Use of Biota, Sediments and Water in Environmental Monitoring*, edited by Deborah Chapman (Chapman, 1996) and the supporting handbook *Water Quality Monitoring* (Bartram & Balance, 1996). These foundational documents were the result of the United Nations Educational Scientific and Cultural Organization (UNESCO), World Health Organization (WHO), Food and Agriculture Organization of the United Nations (FAO) and International Association for Hydrological Sciences (IAHS), establishing a working group to address natural and anthropogenic changes in water quality. These foundational principles have been used by others such as the World Meteorological Organization (WMO, 2015).

The key elements in the design of a water quality monitoring programme are:

a) A very clear statement of the aims and objectives for the programme taking into account relevant legislation. This is paramount to a successful monitoring programme. These precise objectives must be considered in all other aspects of the programme to ensure economic, temporal, and spatial data efficiency.

b) Clarity on information expectations and intended uses of the information. The information collected must be sufficient, but not excessive for the multi-objective requirements of all interested parties, both for the present and for the foreseeable future.

c) An accurate description of the study area concerned. Definition of the area to be monitored, environmental conditions, anthropogenic processes, and water bodies must all be considered with reference to the original objectives and future possible requirements.

d) An adequate preliminary survey and robust sampling sites. A preliminary survey or pilot project may be necessary to test assumptions, sampling sites, parameters to be tested, or times. These will also help to define the practicalities and safety aspects.

e) Appropriate water quality variables to be measured. The precise aims and objectives will dictate which parameters are to be measured, as well as the current and proposed legislation. Historic and current data will influence the parameter choice to attain a cohesive and integrated programme. The number of parameters, and the use of indicators (e.g., *E. coli* for bacterial contamination) will need to be considered to keep the water quality monitoring programme within a realistic budget.

f) Appropriate frequency and timing of sampling. The preliminary survey, any specific characteristics such as natural variability, historic events, costs and the current legislation will indicate frequency and timing of samples.

g) Limitations on available resources required for the design. Close attention to the objectives and requirements of all stakeholders is necessary to attain an efficient, robust, integrated monitoring programme of benefit to all within a realistic budget (adapted from Bartram & Balance, 1996).

In 2016, MfE identified the area of *uncertainty*, as it pertains to monitoring and management of freshwater (MfE, 2016b), as another aspect of importance in relation to the monitoring of water quality. The understanding of this uncertainty, both temporal, spatial and for methodology is very important to a robust integrated monitoring design. This draft document (MfE, 2016b) identifies three aspects: (1) natural variability (an inherent part of the environment), (2) model and parameter uncertainty, and (3) deep uncertainty. Some of the present monitoring programmes were established under the original systems and a review to incorporate this current legislation aims to ensure further longevity and robustness.

1.3.1 Lake water quality monitoring in New Zealand

The conditions of our lakes, rivers, streams, wetlands and groundwater are nationally important, not only as part of our identity, but because our economy relies on plentiful clean water. Water quality monitoring programmes are an essential part of the management of this most precious resource and now come under part of the Environmental Reporting Act 2015, in the category of "Freshwater pressure and state topics" (MfE, 2016e). In Canterbury, ECan and Ngāi Tahu reiterate the inter-connectedness of all waterbodies, and in particular, lakes within each catchment area with their "Everything is Connected" and "ki uta ki tai" (from the mountains to the sea) initiatives. The 2017 OECD recommendation for the implementation of the NPS-FM is to ensure that water quantity and quality limits (set locally) are comprehensive and ambitious enough to achieve national ecosystem objectives and public expectations (OECD, 2017).

New Zealand has a number of different agencies who have carried out lake water quality monitoring. Regional and unitary councils, National Institute of Water and Atmospheric Research (NIWA), Institute of Geological and Nuclear Sciences (GNS), universities, iwi, and many community interest groups all monitor a variety of different water bodies, for different attributes (MfE, 2017a). NIWA and regional councils currently monitor 4% of the lakes in New Zealand (65 lakes), using the trophic level index (TLI) to assess water quality state.

Five National Environmental Indicators are used for reporting on New Zealand's fresh water: river water quality, lake water quality, groundwater quality, recreational water quality and freshwater demand. These indicators give a picture of the overall health of fresh water in New Zealand. These indicators do not address social, economic and heritage aspects but are used to show the state of the water body, or as a base for further metadata.

The health of waterbodies from a Māori perspective, is measured by many local iwi and hapū using the cultural health index (Tipa & Tairney, 2006), as well as data from NIWA for fish numbers (MfE, 2015). Classification of water bodies provides a framework for context, significance and management by grouping together areas with similar characteristics (Woods & Howard-Williams, 2004). Water quality is found to be poorest in waterbodies downstream of catchments where land use intensification is increasing (e.g., the catchment of Te Waihora; Larned et al., 2016). These findings are particularly relevant to the catchments of intermittently closed and open lagoons and lakes (ICOLLs), such as Te Waihora, as pointed out by Haines (2006) who found that ICOLLs are the waterbodies most susceptible to anthropogenic land-use intensification.

1.4 ICOLLs and their management

ICOLLs are found in the southeast of Australia, South Africa, New Zealand (Figure 1-6), Mexico and the Atlantic coast of Brazil and Uruguay. These water bodies are barrier type coastal waters, are brackish and have a connection to the ocean, which is closed or opened periodically (Haines, 2006). ICOLLs, also known as Temporarily Open/Closed Estuaries (TOCEs) in South Africa, are unique and distinctly different to open estuaries. Most ICOLLs occupy low-lying inter-fan depressions, often draining smaller 'foothills' rivers (Kirk & Lauder, 2000).

Kirk & Lauder (2000) state (confirmed by MfE [2017a]) that the ICOLLs in the South Island of New Zealand form an interlinked chain of habitats that run the length of the east coast from Wairau and Lake Grassmere in Marlborough to Te Waihora and Coopers

Lagoon in Canterbury, and on to Waituna in Southland (Figure 1-6). As previously stated, this most sensitive type of water body (Haines, 2006) has the key issues of pressures within the catchment, future climate change, and increased lake amenity demands. Kirk and Lauder (2000) also state that there is still a “dearth of studies” particularly for long-term management for ICOLLs and that this scarcity of literature is due to the unique character, situation, and use of each ICOLL.

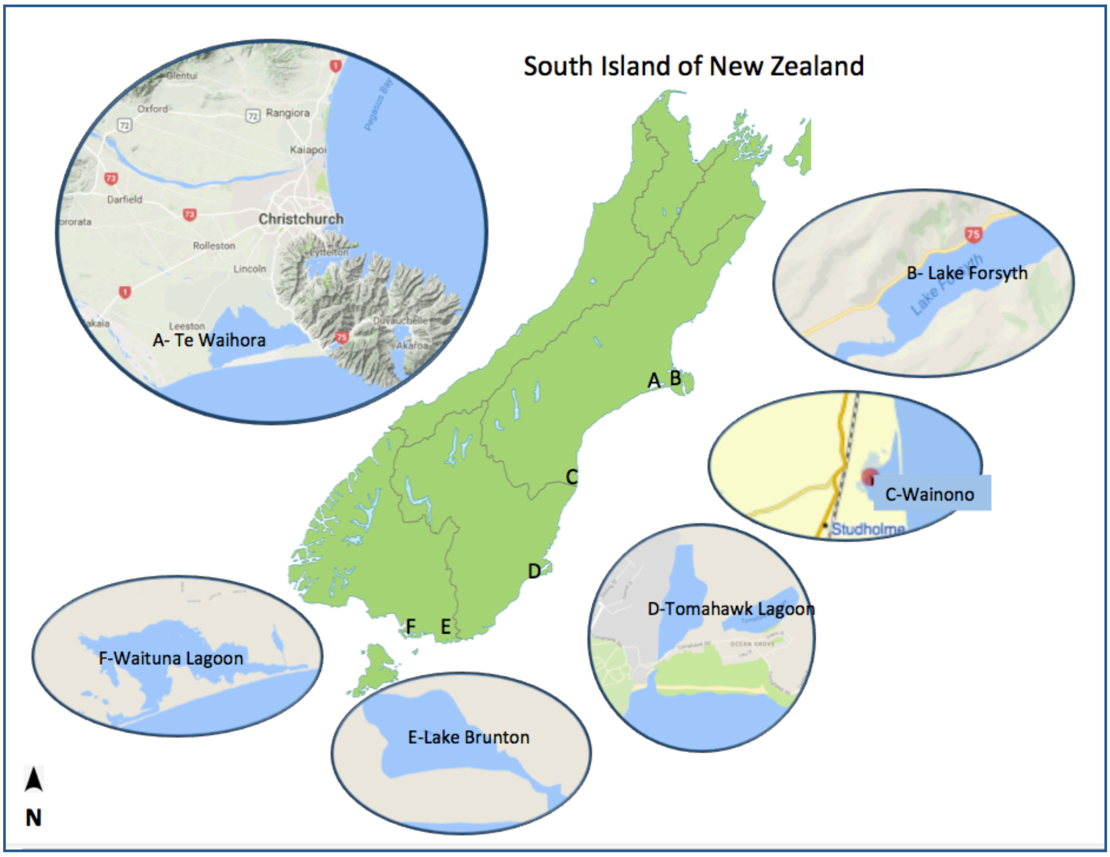

Figure 1-6: ICOLLs in the South Island of New Zealand (compiled 2017).

In 2012, a literature review of the eutrophication of coastal lagoons (Schallenberg & Schallenberg, 2012) was compiled specifically to help the management of Waituna Lagoon in Southland, New Zealand. It documents published literature from international ICOLLs where in-depth studies of ICOLL processes have been carried out. These studies point out that some ICOLLs have similar characteristics, but the majority, and in particular Te Waihora/Lake Ellesmere, exhibit some distinct differences. It is therefore very difficult to apply data and potential management solutions from one ICOLL to another.

To develop correct management strategies, a fundamental understanding of all aspects of an ICOLL and in particular, the mixing and circulation characteristics, is imperative. Kirk and Lauder (2000) note that comparatively low fluvial inflow of some ICOLLs will have strong management significance. Water residence time is relatively long, and they postulate this will result in a generally small capacity for either hydrologic or sedimentological storage. Change in land use will therefore be quickly reflected in changes to these regimes. Additionally, a high proportion of sediment will be fine sediment, leading to the ICOLL becoming silt- or mud-dominant, particularly close to the inflows. Anthony et al. (2009) outline possible scenarios of the effects of climate change on the physical, social and ecological dimensions and note that for mid-latitude lagoons in the USA, longer term stability is linked to the relationship between sedimentation and sea levels, and that may be an aspect to consider when addressing climate change effects on ICOLL management.

As previously stated, in 2016, the proposed *Next Steps for Freshwater* document (MfE, 2016a) clarified that ICOLLs are to be managed as freshwater bodies, according to Appendix 2 of the NPS-FM (2014). This proposes that ICOLLs have the same water quality attributes, including their "national bottom lines" for water quality assessment, as all other lakes, in the hope that it will prevent any further degradation of an ICOLL.

1.5 Te Waihora/Lake Ellesmere

Te Waihora/Lake Ellesmere is an ICOLL in Canterbury, New Zealand (Figure 1-6). It is New Zealand's fifth-largest lake covering approx. 20,000 hectares, has an average depth of 1.4 m, with a maximum depth of 2.7 m and a catchment of 276,000 hectares. It is within the area bounded by the Rakaia River, the Waimakariri River and the Southern Alps, on the east coast of the South Island (Figure 1-7; DOC, 2016).

1.5.1 History of Te Waihora

Te Waihora/Lake Ellesmere was formed following the last ice age (ECan, 2002). Two glacial fans (Rakaia and Waimakariri) with the upper Selwyn River (not glacier-fed) flowing to the south-east between these fans built the Canterbury Plains, which has resulted in a complex groundwater system underlying these plains (Figure 1-8; Anderson, 1994)

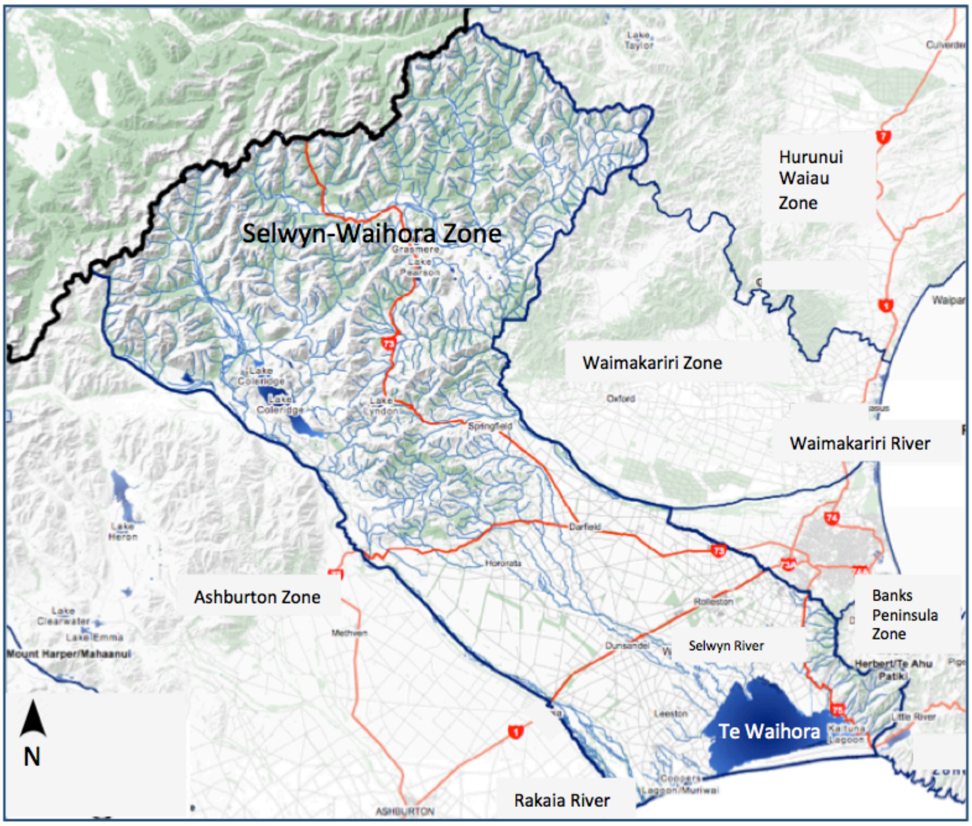

Figure 1-7: The Selwyn-Waihora Zone showing the natural boundaries of the Rakaia and Waimakariri Rivers (adapted from Canterbury Maps, 2017).

Kirk and Lauder (2000) describe the formation of Te Waihora as beginning as a part of these Canterbury Plains fans, then a bay, followed by an estuary, until the last 500 years, when it became a large shallow coastal lake.

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Figure 1-8: Schematic oblique view cross section, looking northwest, showing alluvial fan structure of the Selwyn plains (Anderson, 1994)

Kitto (2010) describes Te Waihora as a freshwater lake, low in nutrients c. 7500 years ago, with the Waimakariri flowing to the sea through this area as recently as 500 to 600 years ago. This is confirmed also by Hemmingsen (1997). The Ngāi Tahu name of Te Waihora means “water spread out”, which accurately describes this water body (Hughey et al., 2013).

The catchment of Te Waihora is within the area bounded (approximately) in the south by the Rakaia River, in the north by the Waimakariri River and stretches across the Canterbury Plains from the foothills of the Southern Alps to the coast. The north-eastern portion is bounded by the volcanic hills of Banks Peninsula (Figure 1-7; ECan, 2002). There are three contrasting geological zones: the western foothills (older sedimentary and younger volcanic rocks) which comprise the headwaters of the Selwyn River (and its tributaries, the Waianiwaniwa, Hororata and Hawkins), the alluvial gravels of the Canterbury Plains making up three-quarters of the catchment, and the volcanics of Banks Peninsula in the east (ECan, 2002).

This formation (within the last 5000 years) involved a sequence of coastal changes at the same time. What is known as the Kaitorete Spit (dividing the lake from the sea) was formed by sand and shingle drift from the rivers in the south, transported up the coast by the powerful southerly sea action. This spit is not correctly a spit, but more accurately a *barrier beach* (Kirk & Lauder, 2000). Kaitorete Spit forms the south-eastern boundary with the sea. It is 26 km long, 5 m high and 3.2 km wide, narrowing to 200 m at Taumutu where the artificial openings occur (ECan, 2002).

Due to the complex actions of the strong southerly waves and the materials being transported northward, the coastline has changed significantly over a geologically short period of time (Kitto, 2010). There has been a build-up at the Banks Peninsula end and erosion of the coastline towards the south, having a pivotal point near Taumutu (Renwick et al., 2010). The remnants of a podocarp forest can still be seen on the beach near Taumutu showing the continuing and significant effect of southerly winds, sea and climate patterns on this whole area including the lake (Figure 1-9). These shoreline shifts affect the position and size of the barrier.

Figure 1-9: Remnants of a native forest visible on Taumutu Beach (2015).

A feature worthy of note by Kirk and Lauder (2000) is the "birds-foot" delta built up by the Selwyn River as a result of the sediment-laden river flowing into the shallow coastal "sink". The lake area has been up to twice its present size (area and depth) at different times in its history (Kirk & Lauder, 2000). This foundational system, plus anthropogenic adaptations for drainage and additional waterways in drier areas, has resulted in the current waterway systems, which are a major factor in the water balance of Te Waihora.

Beech-dominated forest is thought to have covered much of this catchment, but burning allowed kānuka (Kunzea ericoides), cabbage trees (Cordyline australis) and kōwhai (Sophora) to take over (ECan, 2002). When Henry Kemp (the Crown's representative sent by Governor Grey) arrived in 1848, much of the catchment had become a large open grassland and swamp. The settlers drained the swamps and wetlands in the vicinity of the lake to enable cultivation of the fertile soils (Taylor, 1996) and constructed water races on the inland plains for human and stock water. The current anthropogenic use has changed in recent years as irrigation has enabled intensification of the land for predominantly agricultural purposes. Macrophytes (*ruppia* sp.) predominated within the lake, but the storms of 1968 and 1982 largely removed this plant (ECan, 2002).

Te Waihora is internationally significant for its abundant and diverse wildlife and nationally important salt-marsh vegetation (Taylor, 1996). It is highly valued as a tribal taonga, illustrated by its initial name of Te Kete Ika o Rākaihautū (the food basket of Rākaihautū; Tipa & Associates, 2013). Te Waihora holds a central place for Ngāi Tahu values, culture and social order (ECan, 2013).

A National Water Conservation Order for Te Waihora/Lake Ellesmere, was declared in 1990 (National Water Conservation Order, 1990). The outstanding values of the lake (added to the the WCO when it was amended in 2011) are recognized as: habitat for wildlife, indigenous wetland vegetation, and fish; and as being of significance in accordance with tikanga Māori in respect to Ngāi Tahu history, mahinga kai and customary fisheries (Lomax et al., 2015). As a part of the Ngāi Tahu Waitangi Tribunal claim settlement, the bed of Te Waihora was vested in Te Rūnanga o Ngāi Tahu. The Māori concept of hauora aligns with the current New Zealand legislative view of groundwater and surface water resources as a single linked unit and part of a whole, integrated system to be considered when monitoring and managing (Taylor, 1996; Woods & Howard-Williams, 2004).

1.5.2 Hydrology of Te Waihora

Surface water inflow, groundwater inflow, rainfall and seawater are the predominant inflows of water to Te Waihora (Renwick et al., 2010). Figure 1-10 shows the water balance from 1987 to 2007. The surface water inflow comes from the Banks Peninsula rain-fed streams and the spring-fed lowland tributaries (although the Selwyn River is a foothills-fed river, its intermittent nature results in it being mainly spring-fed in its lower reaches). This results in 65% of the inflow from streams, drains and rivers (Clausen & Horrell, 2007). This surface water includes not only the streams and rivers, but water races (which often discharge into tributaries) to supply stock water, and drains to enable farming activities in the very wet lowland areas. ECan (2015) state that the flows (and flowing tributaries) are changing, which may result in a different water balance in the future, requiring changes to monitoring and management protocols. Climate change may result in a change in evapotranspiration and rainfall.

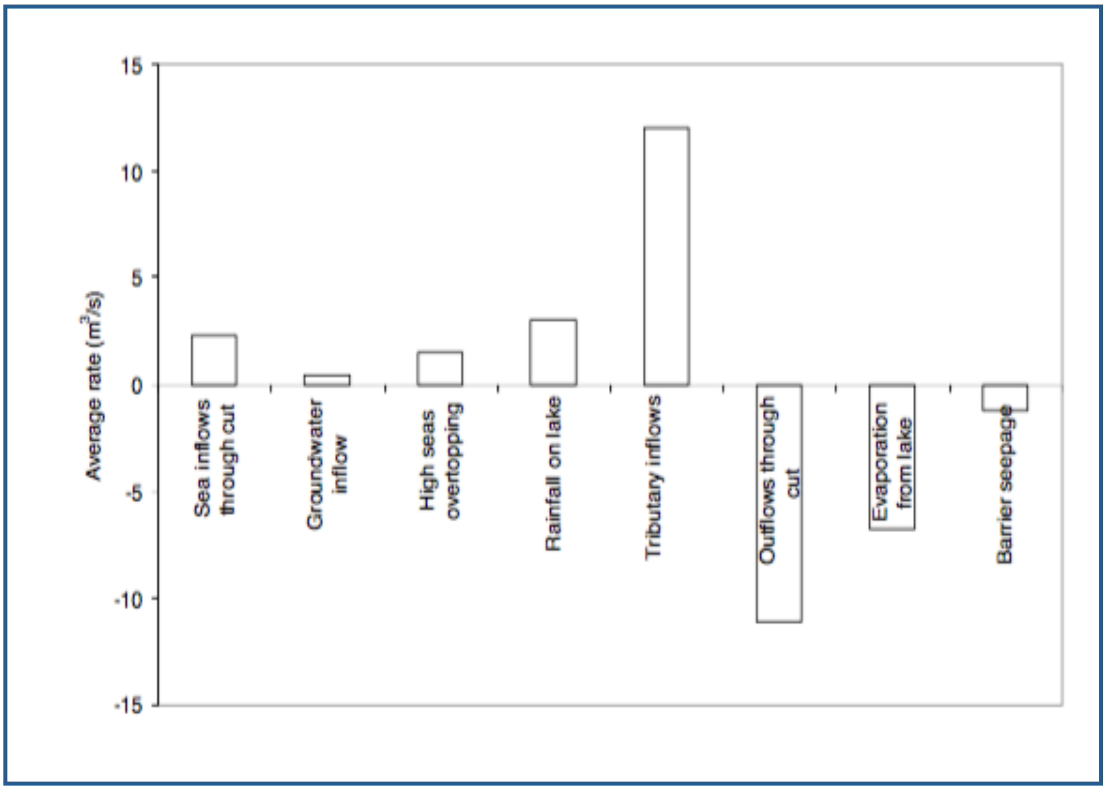

Figure 1-10: Average rate of various inputs and outputs to Te Waihora 1987-2007 (Renwick et al., 2010).

The springs feeding the tributaries are groundwater-sourced from the underlying aquifers of the catchment and will reflect the water quality of this groundwater. The groundwater flow is from the northwest towards the coast (ECan, 2002). It is replenished from rainfall in the foothills and in the catchment area, with some infiltration from the Rakaia and Waimakariri Rivers as shown in Figure 1-11 (Taylor, 1996). These physical elements of the spring-fed/groundwater system and rain-fed streams, along with seawater, are an integral part of the complexity of the water quality and quantity (current and potential) contributing to the inflows of the lake. Williams and Aitchison-Earl (2006) found a good relationship (for water quantity) between the stream flows and the local groundwater levels in wells. Williams (2010) concluded that the relationship between groundwater levels and spring-fed streams is affected by both climate and groundwater abstraction. ECan (2002) state that historically, the most significant aspect of surface water flow is that it is highly variable. During the latter months of the year, it may be zero as it relies on stored groundwater. Land-use intensification within the catchment (abstraction and diffuse pollution) may also affect the inflows to Te Waihora for both water quantity and quality.

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Figure 1-11: Elements of the groundwater balance in the Te Waihora catchment. (MCM yr^{-1} – million cubic metres per year; Taylor, 1996).

Kaitiakitanga (the stewardship role of Māori) has long recognized the importance of the lake level to mahinga kai (traditional food gathering). The importance of the level of the lake is recognized also today for many reasons: for example the ecology of the lake, and the effect on the special features outlined in the NWCO. Te Waihora has a long history of opening an artificial outlet to the sea from pre-European days as well as when much of the land surrounding the lake was drained to enable historic and present day farming to occur. There is no natural outlet to the sea, requiring present day artificial openings to be carried out according to set protocols, using heavy earth-moving machinery at high risk and high cost.

The NWCO, updated in 2011, regulates the lake levels (NWCO, 1990). The minimum levels, where an opening can be attempted, are 1.05 m.a.s.l. (1 August to 31 March); 1.13 masl. (1 April to 31 July); any level (15 September to 15 October and 1 April to 15 June). A protocol committee comprised of Te Rūnanga o Ngāi Tahu (TRoNT), Te Taumutu

Rūnanga, Department of Conservation (DOC), Selwyn District Council Rating Committee, Fish and Game NZ, Commercial Fishermen's Association, Selwyn District Council (SDC), Christchurch City Council (CCC) and Waihora Ellesmere Trust (WET) liaise with the consent holders (TRoNT and ECan) when they make decisions to open the lake (Lomax et al., 2015). The lake opening regime is a part of the positive interventions for the adaptive management of improvement initiatives for Te Waihora. Operational flexibility of the lake level, time of the lake being open and salinity conditions, all affect the fish passage, macrophytes restoration, lakeside land flooding, nuisance and toxic bloom management, bird habitat, salt-marsh vegetation and salt-sensitive weed control (ECan, 2013). Figure 1-12 shows the water level within the lake and the number of openings per year. The lake opening is usually naturally closed due to southerly storms and wave action bringing gravel into the gap. During long periods of an opening, seawater may increase the lake salinity by 20%, especially around the Taumutu area. A critical aspect for the timing of the openings relates to fish migration for spawning; however the opening/closing regime is complex as higher salinity affects other lake aspects, for example excess salinity may affect *ruppia* growth and toxic algae (ECan, 2002).

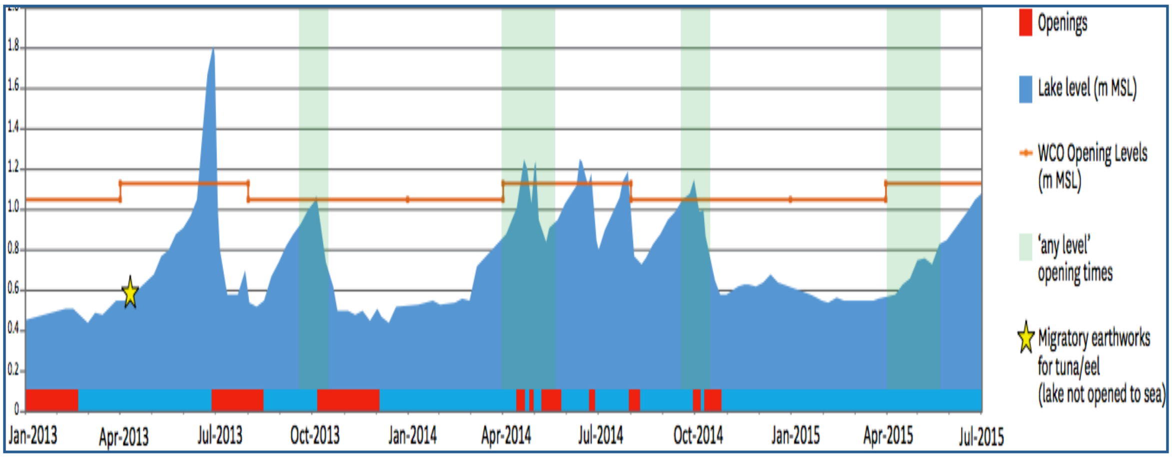


Figure 1-12: Te Waihora water levels (1 Jan 2013 to 30 June 2015) showing effects of opening events (Lomax et al., 2015).

Due to the size and depth of Te Waihora, wind has a major impact on the water level and water quality. Wind can "tilt" the water surface, known as set-up (ECan, 2002), creating a change of half a metre or more and routinely causes a significant decrease in water clarity due to the constant re-suspension of sediments by wind-induced wave action. Winds of up to 100km per hour have been recorded (Kirk & Lauder, 2000). The significant effect of wind on Te Waihora is shown in Figures 1-13, 1-14, and 1-15. All photos are taken from the same situation looking towards Garibaldi Island. Figure 1-14 shows Te Waihora with very little wind. Figures 1-13 and 1-15 are during a strong southerly wind several days later and show clean well-washed pebbles on the lakebed with no obvious macrophytes. Figure 1-13 shows exposed fishing nets due to tilt of the water (photo shows Garibaldi Island just visible in the background).

Figure: 1-13: Te Waihora showing exposed fishing nets and lakebed during a strong southerly wind (photo: B McMillan, May 2013).

As noted, wind has a significant effect on water quality and localized quantity and may result in increased water levels on the opposing side of the lake. It can affect the shoreline, move the sediment on the lake floor, cause localized flooding and cause complex currents within the lake. Figures 1-13, 1-14, 1-15 and Figure 1-9 emphasize the vulnerability of this shallow, large, brackish ICOLL to the localized climatic conditions prevalent in this area. Due to these extreme effects, lake monitoring data must be timely, robust, and specific, and document lake level and other climatic conditions (e.g., rainfall, floods or excessive wind) at sampling times.

Figure 1-14: Te Waihora looking towards Garibaldi Island (photo: B McMillan, May 2013).

Figure 1-15: Te Waihora looking towards Garibaldi Island during a strong southerly wind (photo: B McMillan, May 2013).

1.5.3 Water quality of Te Waihora

As an ICOLL, the water quality of Te Waihora is neither completely freshwater nor estuarine (Taylor, 1996). The lake water is typically 15% to 30% of the salinity of seawater (ECan, 2002; Harding et al., 2004) and, as previously stated; input is from surface water tributaries, rainfall and seawater, resulting in a complex system spatially and temporally (Figure 1-10).

Clarity is one of the main concerns for water quality in Te Waihora (Secchi depth of around 7 to 18 cm; Leipe, 2009). There has been a perception of Te Waihora, as a "dead" lake (possibly due to the high sediment levels), but Hughey et al. (2013) refer to their report as a "health report card" (documenting the state, trends, improvement initiatives and future plans associated with this alive and active water body) in order to initiate a change in the perception of this clarity problem. Wind, as previously noted, is a major factor in the re-suspension of sediment causing increased levels of turbidity, which affect other lake components both positively and negatively, for example, macrophytes fail to thrive in highly turbid water while an increase in algal production may be suppressed in highly turbid situations (Sagar et al., 2004). The main components of the turbidity sources in Te Waihora are shown in Figure 1-16. Figure 1-17 is a graph of the change in clarity (as shown by Secchi depth) of Te Waihora from 2004 to 2016.

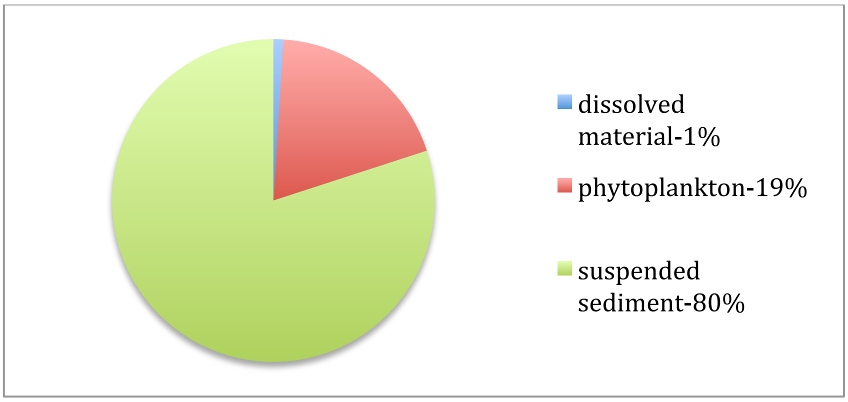


Figure 1-16: Sources of turbidity in Te Waihora (adapted from Hayward, 2010).

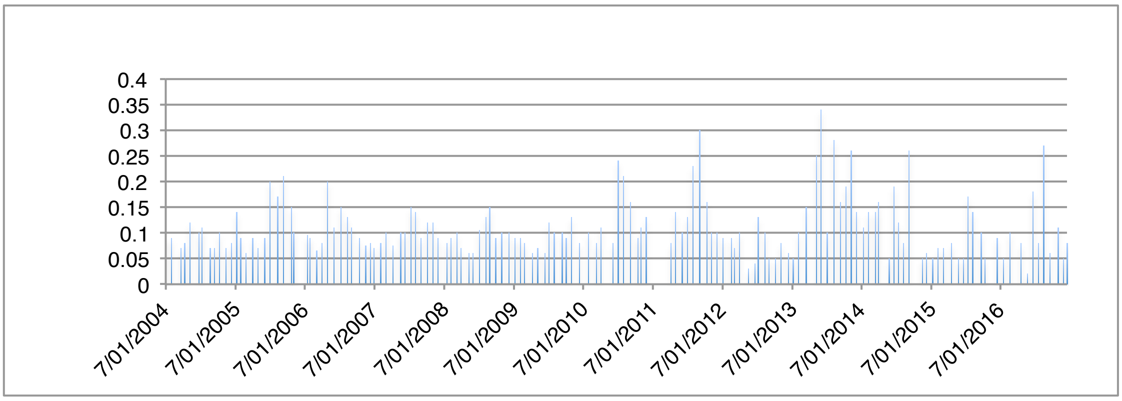


Figure 1-17: Clarity trends 2004 to 2016. Mid-lake secchi depth (metres). (compiled from ECan data, 2017).

One measure of lake water quality is the trophic level index (TLI; MfE, 2017a) shown in Table 1-1. This index is based on chl *a*, clarity, TN and TP. Monitoring of Te Waihora uses a version of this index calculated from chl *a*, TP and TN only (TLI3). Te Waihora falls mainly into the hypertrophic state (Figure 1-18).

Table 1-1: Lake TLI status (Burns et al., 2000).

Lake type	Trophic level	Chl *a* (mg/m^3)	Secchi depth (m)	TP (mg P/m^3)	TN (mg N/m^3)
Ultra-microtrophic	0–1	0.13–0.33	31–24	0.84–1.8	16–34
Microtrophic	1–2	0.33–0.82	24–15	1.8–4.1	34–73
Oligotrophic	2–3	0.82–2.0	15–7.8	4.1–9.0	73–157
Mesotrophic	3–4	2.0–5.0	7.8–3.6	9.0–20	157–337
Eutrophic	4–5	5.0–12	3.6–1.6	20–43	337–725
Supertrophic	5–6	12–31	1.6–0.7	43–96	725–1558
Hypertrophic	6–7	>31	<0.7	>96	>1558

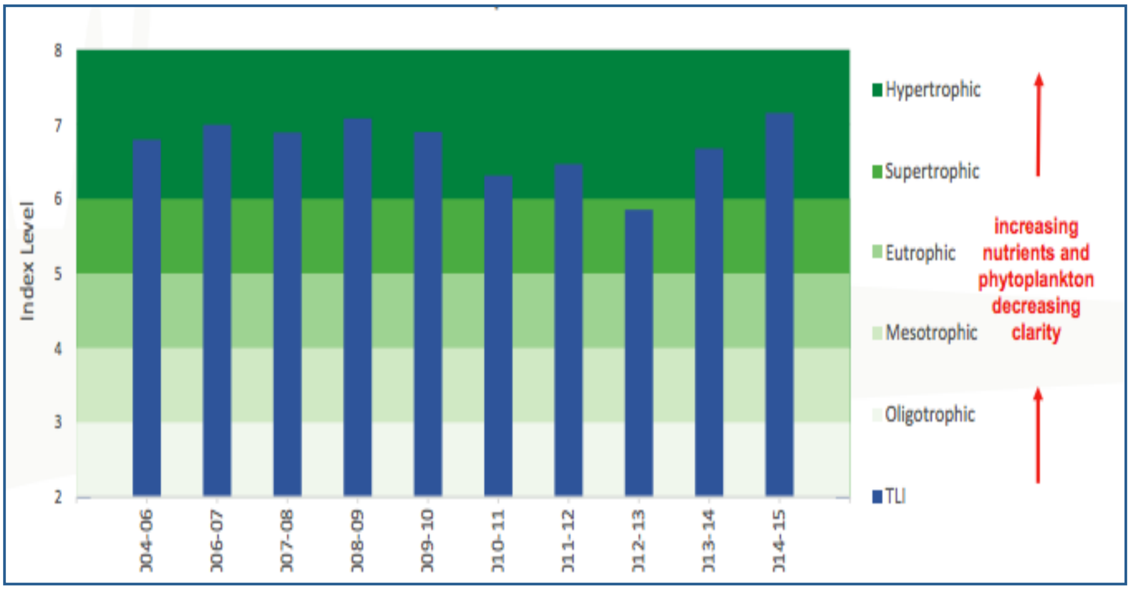


Figure 1-18: Trophic level index for Te Waihora 2004 to 2014 (Lomax et al., 2015).

The predominating chemical species of N and P from the incoming tributaries differ from the predominating species within the lake itself (ECan, 2002). This is confirmed by Schallenberg et al. (2010) and Larned and Schallenberg, (2006) in relation to phytoplankton production. Further research has recently been carried out by Marc Schallenberg examining how N and P loads are processed within the lake, and the interaction between the physical and chemical relationships (e.g., temperature, wind, sediment, oxygen; Schallenberg, 2017). Dissolved oxygen concentration in the lake is generally high but algae production in this nutrient-rich water seems to be less than expected (possibly due to the sediment mixing within the lake; ECan, 2002). The benthic microbial communities of ICOLLS are also an important part of lake functioning, particularly where there is a large surface area relative to lake volume (Highton et al., 2016).

1.5.4 Te Waihora ecology

The zone of wetlands surrounding the lake was historically more extensive than it is today. Raupo (Typha orientalis), flax, toetoe (Austroderia), sedges and rushes dominated it. Wetlands are important culturally, and for bird-life, plant habitat and vegetation (ECan, 2002). Some decades ago, the upper zone of the wetlands was converted to pasture, but current improvement initiatives are to reinstate and increase wetland areas (ECan, 2011). These areas are affected by the water quality (e.g., salinity) of Te Waihora with the flow-on effect on wildlife.

Wildlife in and around Te Waihora includes wetland birds, lizards, and aquatic and terrestrial invertebrates. Up to 98,000 wetland birds may be present on the lake at any one time (Taylor, 1996), but more current tallies quote 30,000 to 40,000 birds. The highest bird numbers (2013) for any New Zealand lake have been noted (Lomax et al., 2015). The lake is an important migration staging post for a number of migratory and indigenous waders. There can however be an overabundance of some bird species (e.g., Canada geese) causing over-grazing of the vegetation and pollution of the water (Lomax et al., 2015).

1.5.5 Lake use

Te Waihora is used extensively for private recreation with a wide range of activities carried out currently and historically, both within the environs of the lake and on the lake itself. Boating, surfing, skiing, kayaking, shooting, picnicking, birdwatching, photography, water-fowl hunting, trout angling, whitebaiting, cycling, walking, to name some of these (Lomax et al., 2015). Tourism has an increasing role in the activities of the area.

Commercial fishermen, fishing for tuna/eels, pātiki/flounder and aua/mullet play a large part economically (SDC, 2017). The MPI quota management system ensures sustainability of these species. Te Waihora has recorded 47 different fish species, which signifies a productive “living” lake (Ford et al., 2017).

1.5.6 Catchment drainage and water-race systems

Land drainage for settlement and agriculture began in the mid-1880s. In the lower catchment area, SDC currently administer seven drainage schemes, while ECan administers one scheme (Table 1-2 and Figure 1-19). A small reach of the Taumutu scheme joins the Waikekewai Creek. The Halswell drainage system has been extended and upgraded with the objectives of (1) efficient economic drainage, (2) control of lateral and bed erosion of drains, and (3) maintenance of the cross section shape and grade of the drains, their main purpose being to remove rain water from the adjacent land (ECan, 2013). Additionally, many private drains feed into the council drains. Te Waihora tributaries are a combination of this drainage system and historic streams. The Banks Peninsula sub-catchments on the eastern side of Te Waihora make up approximately one-third of the lower catchment area, but they contribute over three-quarters of the total peak rainfall flow. The southerly/ south-easterly storms on the hills of Banks Peninsula create high rainfall peak flows (ECan, 2013).

The Selwyn–Waihora Zone Committee’s recommendation 5 (further described in section 1.7) requires additional support for farmers for effective drain management for stock exclusion, and planning and planting along drain margins. SDC and ECan must ensure the drains continue to function as drains. The Sustainable Drain Management Project, is an initiative from WET, including ECan, SDC, Ngāi Tahu, Lincoln University, and the local community for a shared understanding of the drainage network and current management practices. The main purpose is to reduce phosphorus and microbial contamination by allowing particulates to drop out of run-off and also to achieve shading along the drains. Recommendation 5 also includes investigation of sediment retention options and targeted in-stream sediment removal.

Table 1-2: Drainage schemes in the lower Te Waihora catchment area (CPWL, 2015).

Scheme	Length of drain(km)	Area served(ha)	Properties served
Taumutu	8.2	500	14
Taumutu culverts	4 culverts	1000	200
Leeston	207.9	12847	393
Leeston township	3.9	89.9	640
Ellesmere	25.7	1329	74
L II	64.6	5068	1055
Greenpark	21.2	2433	90
Osbornes	9.5	1256	49
Halswell	156	11700	

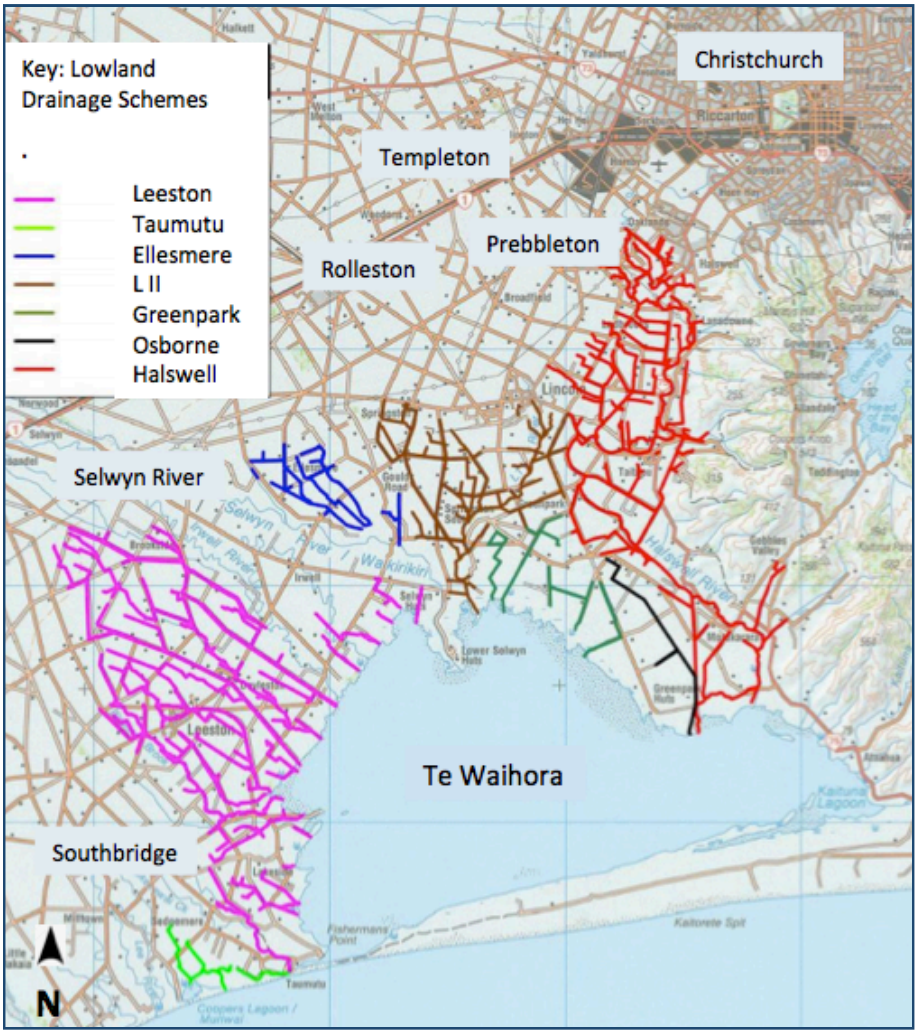


Figure 1-19: Drainage networks in the lower Te Waihora catchment area (CPWL, 2015).

Map scale approximately 1 cm to 4 km.

Storm water and waste water

Storm water and waste water are both a part of the SDC 5-waters activity and management systems. SDC is responsible for 14 reticulated waste-water systems servicing 55% of properties within the district (SDC, 2016a). The Eastern Selwyn Sewerage Scheme serves the townships of Rolleston, Lincoln, Prebbleton, Springston, and West Melton. Their disposal area is 480 ha. (sited in the Burnham/Rolleston area), with capacity to increase for future needs. Tai Tapu sewerage is pumped to the CCC sewerage scheme. Discharges in the lowland area having direct potentially negative effects are the Ellesmere Sewerage Scheme (serving Leeston, Southbridge and Doyleston with a disposal area of 15.7ha.) and storm-water drainage from Lincoln. Some of the storm-water systems within the older towns were constructed with older technology.

Many individual septic tank systems operate throughout the catchment, resulting in limited diffuse pollution within that local area. Figure 1- 20 shows the density of on-site waste-water discharge. One specific area where concern has been expressed regarding septic tank discharge is around the Snake Creek/Silverstream catchment. Some research to establish the source of contamination has been carried out involving local pollution or the effects from the Eastern Selwyn Sewerage Scheme, but no conclusive results were found (Robinson, 2013).

Any significant diffuse pollution effects will be captured cumulatively by the tributaries discharging into Te Waihora, or will affect the water quality of the aquifers of the catchment. Hot spots within the catchment have been recognised but relate more to their immediate area (e.g., swimming at Coes Ford) rather than to the lake itself. Emerging contaminants (as described in 4.4.1 pg 130) may be a potential pollutant for Te Waihora, but to date little contamination has been found (ECan, 2002).

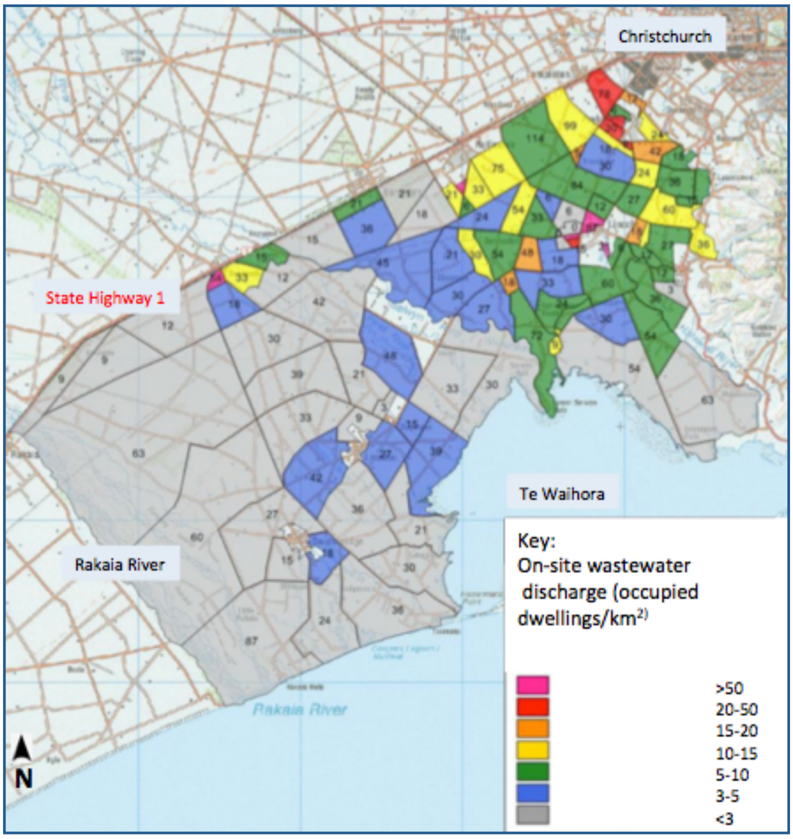


Figure 1-20: Waste-water discharge density in the lower Te Waihora catchment area for 2013 census (CPWL, 2015). Map scale approximately 1 cm to 5 km.

Water-race systems

The water-race system was created to supply drinking water for stock animals and rural households before groundwater was available on the inland plains. Their secondary purposes are firefighting, landscape/aesthetic and irrigation (SDC, 2017). Some water races flow into the Te Waihora tributaries as they flow east, while others terminate by flowing into groundwater.

The water-race network (Figure 1-21) receives water from both the Rakaia River and the Waimakariri at a consented rate of 6.1 m^3/s (ECan, 2013). SDC has three water-race systems within the Selwyn–Waihora catchment; the Ellesmere system (62.6 million m^3), the Malvern system (36.2 million m^3) and the Paparua system (41.3 million m^3) (annual average quantity of water used).

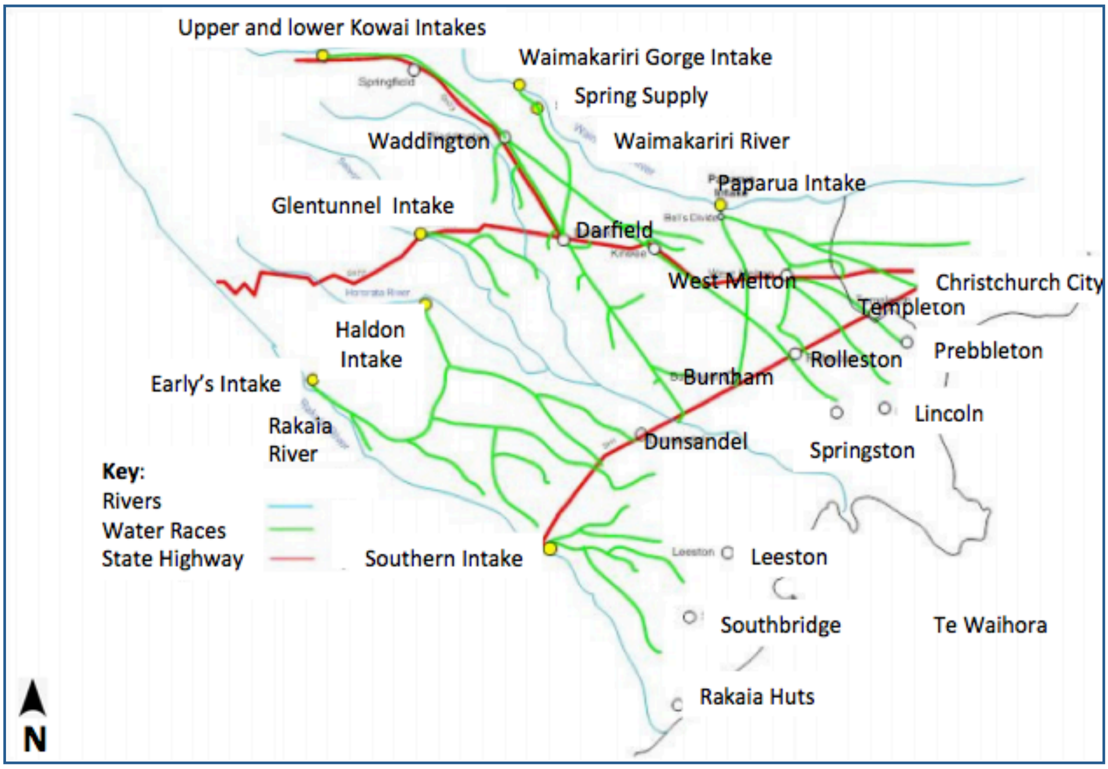


Figure 1-21: A schematic of water races in the Selwyn-Rakaia catchment (SDC, 2017a).

1.5.7 Water use in the Te Waihora catchment

There are approximately 80 surface water consents and nearly 1700 groundwater consents in the Selwyn–Waihora catchment, of which 80% do not expire until after 2030. This consented volume is 30% to 40% above the Natural Resources Regional Plan (NRRP) allocation limit but it is estimated that only approximately half of the consented volume is actually used (ECan, 2013).

Managed aquifer recharge (MAR) and targeted stream augmentation for environmental benefit are both water uses within this catchment set out in the Selwyn–Waihora Zone Committee's Zone Implementation Programme (ZIP) Addendum (further described in section 1.6). Both activities require further consultation or technical work and may include water associated with CPWL.

Water use and the resulting effect on water quality in terms of increasing nitrate concentrations in shallow groundwater (relevant to spring-fed lowland streams), accumulated phosphorus in the lakebed sediments (and the need to address this for improvement initiatives), the decreasing health of Te Waihora, CPWL irrigation development and the water quality decline due to the lag in the groundwater system, are all outlined in the ZIP Addendum (ECan, 2013) as further described in section 1.6.

1.5.8 Te Waihora catchment land use

Land use within the Te Waihora catchment is the most significant area creating pressure on the waterway systems. The cumulative impacts of diffuse pollution over large areas with lag-time effects are one of the main challenges facing catchment management (Hughey et al., 2013). The percentage change of major land-use classes is shown in Table 1-3. Historically, the inland plains were dry-land sheep and crops, but current data shows the entire catchment currently has a similar land use (Figures 1-22a and 1-22b). This is confirmed in Figure 1-23, which shows the irrigated areas and types of irrigation systems operating across the Te Waihora catchment.

Table 1-3: Te Waihora catchment change in land-use class (Lomax et al., 2015).

Land use class	2003	2013	2015
Dry stock	58%	51%	49%
Dairy	18%	22%	25%
Crop & horticulture	13%	13%	11%
Forestry	5%	4%	4%
Grazing	1%	4%	4%
Lifestyle	1%	3%	3%

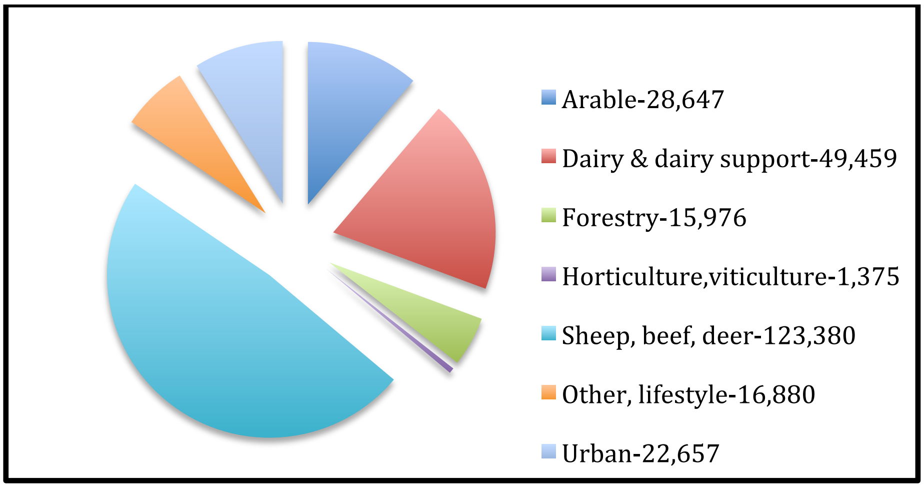


Figure 1-22a: Land use in the whole catchment (258 374 ha) (compiled from Agribase data 2015).

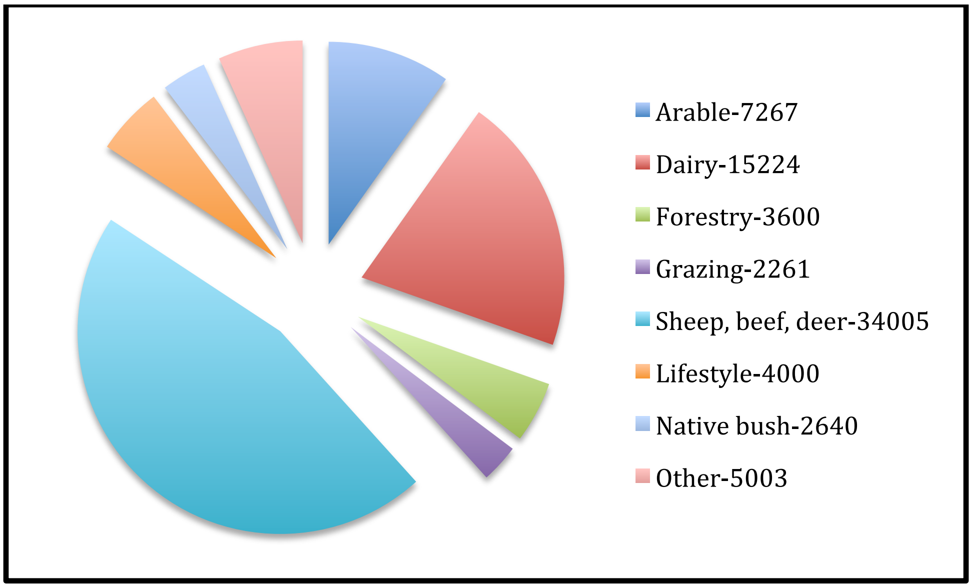


Figure 1-22b: Land use in lower catchment (below Main South Road, 74 000 ha) (compiled from Agribase data 2015).

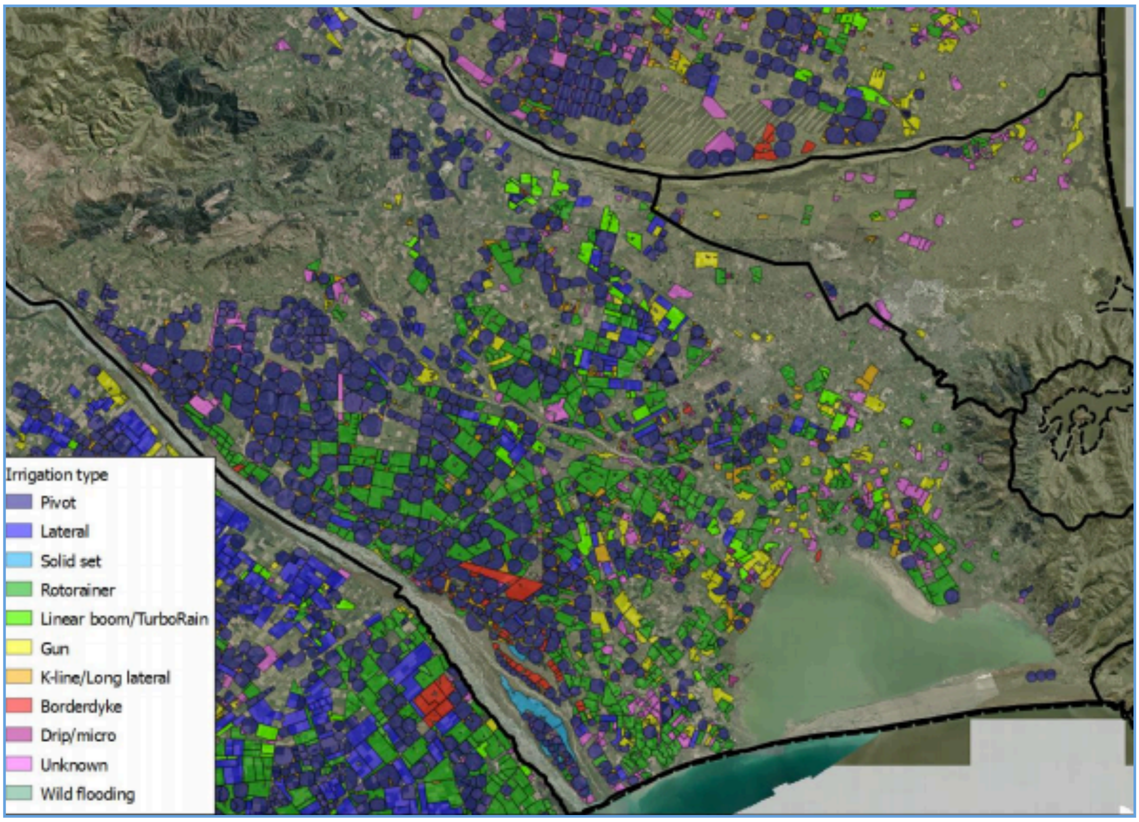


Figure 1-23: Types of irrigation in the Te Waihora catchment (Dark, 2017).

Population

The Selwyn–Waihora catchment is a part of the SDC and CCC local authorities. Selwyn is the nation's fastest growing district (SDC, 2016b) with a population of 44,595 projected to reach 75,000 by 2030 (SDC, 2016b). Christchurch's suburbs of Halswell and Hornby fall within the Te Waihora catchment. Population is expected to grow in both areas, but especially within the Selwyn District. Towns with population greater than 1000 are shown in Figure 1-24.

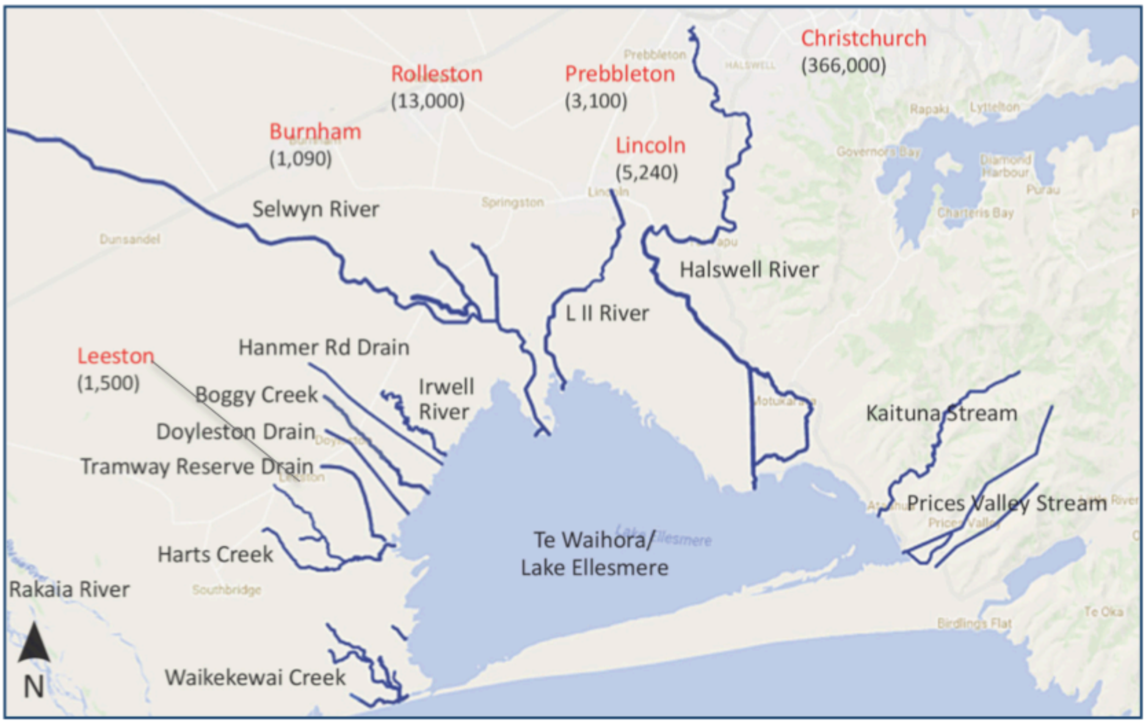


Figure 1-24: Te Waihora showing the lake, its main tributaries and towns (population > 1,000) in the lower catchment (compiled from Canterbury Maps, 2016).
Map scale approximately 1 cm to 5 km.

1.6 Lake Stakeholders and Management

There are numerous entities and stakeholders associated with Te Waihora/Lake Ellesmere, consisting of regulatory bodies, iwi, industry, research, community and environmental groups (Hughey et al., 2013). Figure 1-25 shows the large number, the differing roles and interests and the complexity of the interaction between the entities.

1.6.1 Regulatory Agencies

Central and local government in co-governance with Ngāi Tahu and the local Rūnanga, play an overarching role within this complex system. Te Rūnanga o Ngāi Tahu is the local iwi, with six Papatipu Rūnanga associated with Te Waihora. Te Taumutu Rūnanga is acknowledged as the main kaitiaki (guardian and protector) of Te Waihora/Lake

Ellesmere (Te Rūnanga o Ngāi Tahu, 2016). Ownership of the lakebed was returned to Ngāi Tahu in 1998 as part of the settlement act (1998 Ngāi Tahu Claims Settlement Act). Ngāi Tahu are supportive of the collaborative processes within the Treaty of Waitangi framework (LWF, 2010) and integrally involved in many stakeholder and interest groups.

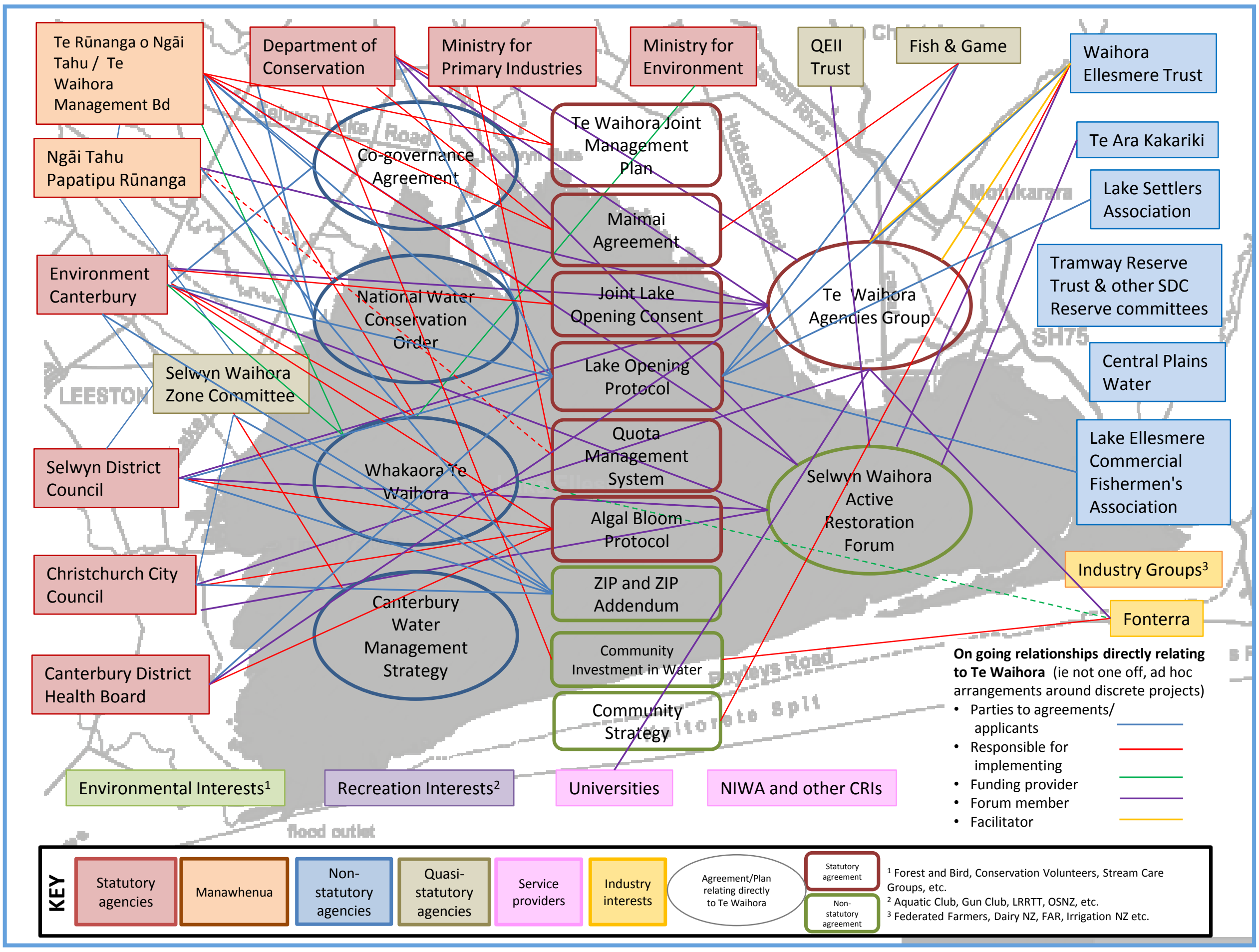


Figure 1-25: This graphic of the Te Waihora Key Stakeholders shows the different categories of interest and emphasises the complexity of stakeholder interactions and their objectives (Lomax, 2016).

Environment Canterbury, the Canterbury Regional Council (ECan) is the regional authority with responsibility for Te Waihora and its catchment. ECan has put in place a framework according to the CWMS for current and future management of fresh water, as noted in 1.2.1. Canterbury has ten water-management zones, of which Selwyn–Waihora is one (ECan, 2009a). The Selwyn–Waihora water zone (Figure 1-7) extends from Te Waihora to the upper Waimakariri basin and the high country around Lake Coleridge.

The overarching vision for Te Waihora is to restore the mauri while maintaining a prosperous land-based economy within the catchment. Ngāi Tahu consider Te Waihora and its margins a taonga due to the high concentration of mahinga kai, wāi tapu and wāi taonga (ECan, 2013).

The Zone Implementation Plan (ZIP) and its addendum were developed in the initial phases of the Selwyn–Waihora Water Zone meetings and reflect the collaborative community engagement of all stakeholders to develop this sub-region section of the Land and Water Regional Plan (LWRP). The ZIP is a document identifying integrated actions to give effect to the CWMS in this zone. It is a living document. These are not statutory plans under the RMA, but are the commitments of the community to achieve an integrated positive outcome. The ZIP outlines an overview of water resources, key principles, management priorities and recommendations, with relevant appendices (ECan, 2011).

The Selwyn–Waihora ZIP outcomes (as outlined in the ZIP Addendum) concerning Te Waihora and its catchment are:

- Thriving communities and sustainable economies
- High quality and secure drinking water
- Best practice nutrient and water management
- Kaitiakitanga is integrated into water management in the zone
- Healthy lowland streams
- Te Waihora is a healthy ecosystem
- Hill-fed waterways support aquatic life and recreation
- Alpine rivers and high-country values are protected
- Enhanced indigenous biodiversity across the zone (ECan, 2013).

The ZIP Addendum, 2013 recommendations (solutions package) have a time frame of approximately 30 years and some critical areas may degrade before they improve.

Recommendation 1 requires all parties to identify and progress funding and implement an action programme. Recommendation 2 will review progress towards the desired outcomes. These recommendations are set out according to the following categories- Water supply, allocation and flow, mahinga kai, wāi taonga, wāi tapu, biodiversity and catchment interventions, water quality and lake interventions.

Selwyn District Council (SDC) and Christchurch City Council (CCC), two of the partners in the CWMS, play a major role in many aspects of Te Waihora and its catchment (SDC, 2016a) and are an integral part of the ongoing implementation of the CWMS through zone committees and ZIP and ZIP addendums (ECan, 2009b).

The Department of Conservation (DOC) own approximately 40% of the lake margin and hold a Joint Management Plan between the Crown and iwi for the lake. This is a statutory document (DOC, 2005).

1.6.2 Interested parties/community groups

Many community organisations, industry groups, research institutes, professional bodies, consultants and restoration programmes are also a part of the interested parties associated with Te Waihora. Many of these groups are integrally involved in the ongoing management within the zone committees as well as other management of the lake (e.g., the opening protocol).

WET is a community organisation dedicated to the improvement of the health and biodiversity of Te Waihora/Lake Ellesmere and its catchment. A ten-year action plan was outlined in 2012 and reviewed in 2015. WET publishes a *State of the Lake* report and holds a Living Lake Symposium biennially (Lomax et al., 2015). WET uses an expanded version of the PSR system in their biennial *State of the Lake* report (Lomax et al., 2015). In 2013, at the Living Lake Symposium, the complexities of governance and management of this lake were noted as making integrated management difficult. WET aims to strengthen links between science, monitoring and management (Hughey et al., 2013).

Whakaora Te Waihora (WTW) is an extensive cultural and ecological restoration and research programme funded by MfE from 2012 to 2017, led by Ngāi Tahu and ECan and joined by SDC (in 2014) and CCC (in 2016). WTW has helped fund (in conjunction with Lincoln University (LU) and WET) a Te Waihora monitoring strategy proposal (Hughey, 2015). It notes that although there is monitoring across the range of values (Hughey et al., 2013) there are many gaps, a lack of integration and no formally agreed strategy to enable regular measurement and reporting to help evaluate the effectiveness of management (Hughey, 2015).

Living Water (Living Water, 2016) is a partnership programme between Fonterra (Fonterra Co-operative Group Ltd) and the Department of Conservation who are working together to improve biodiversity and water quality across New Zealand. The partnership teams are currently focusing on five sensitive catchments, one being the L II /Ararira catchment—a tributary of Te Waihora/Lake Ellesmere (Living Water, 2016). A water quality survey has been carried out by this group.

The Lake Ellesmere Commercial Fishermen's Association, Lake Settlers Association and Fish and Game New Zealand are all stakeholders who make up a part of the group responsible for the opening of the lake.

There are a number of local community groups involved in enhancement of their streams and catchment areas (some have carried out surveys of water quality). Examples of these are the Harts Creek Streamcare Group, Tramway Reserve Trust, other Reserve Committees and others.

1.6.3 Education and research

Crown Research Institutes (CRIs) and private consultants, for example NIWA and others, have carried out numerous research initiatives and projects for interested parties (including ECan) and stakeholders of Te Waihora, for example *Te Waihora (Lake Ellesmere) water balance modelling* (Horrell, 2011) carried out for ECan, or *Monitoring and Review Project-Gap Analysis* (Beca, 2012) for MfE.

The Waterways Centre for Freshwater Management is a teaching and research centre based at both the University of Canterbury (UC) and Lincoln University (LU). This centre has been integrally involved with many of the Te Waihora/ Lake Ellesmere projects. Much research and monitoring are carried out as part of teaching and student research projects and there is a desire to extend collaborative participation in all facets of water quality concerns and implementation (Waterways, 2016). Both UC and LU also have other departments/academics with research/monitoring programmes, for example Canterbury Waterway Rehabilitation Experiment (CAREX) is a stakeholder-driven region-wide stream restoration experiment, associated primarily with UC and funded by a charitable trust.

1.6.4 Consent holders

There are numerous consent holders who are required to carry out water quality monitoring within the Te Waihora catchment. The most significant surface water consent holder (and stakeholder) is Central Plains Water Limited. This company is integrally a part of the ZIP and ZIP Addendum as well as a major stakeholder in the future of Te Waihora and its catchment (ECan, 2013). Other significant consent holders will contribute to changes in groundwater quality (e.g., factories, industry, land-use intensification) and contribute to the cumulative groundwater input to Te Waihora (refer Figure 1-10). The anticipated change in water quality as evident in the water quality of the lowland springs feeding the lowland streams, is commonly referred to as due to nutrients "in the post" (ECan, 2013).

CPWL are currently developing an irrigation scheme of approximately 60,000ha on the inland plains between the Rakaia and Waimakariri Rivers. Figure 1-26 outlines the three stages of the plan. CPWL has a resource consent, which includes a programme to monitor and manage the environmental effects of the scheme. Models have been used to postulate the effects of this scheme. CPWL has implemented a monitoring programme with the rationale to determine the impacts of the CPWL scheme as accurately as possible. CPWL is also referred to in the CWMS "solutions package" (ECan, 2013). The scheme is predicted to provide additional recharge to the catchment from alpine rivers, reduce the volume of groundwater used for irrigation, as well as improve lowland stream flow, but may also impact on drainage in the lowland area. The increased volumes of water may dilute nitrogen concentration in Te Waihora but groundwater nutrient enrichment due to land use intensification may be a major aspect of concern.

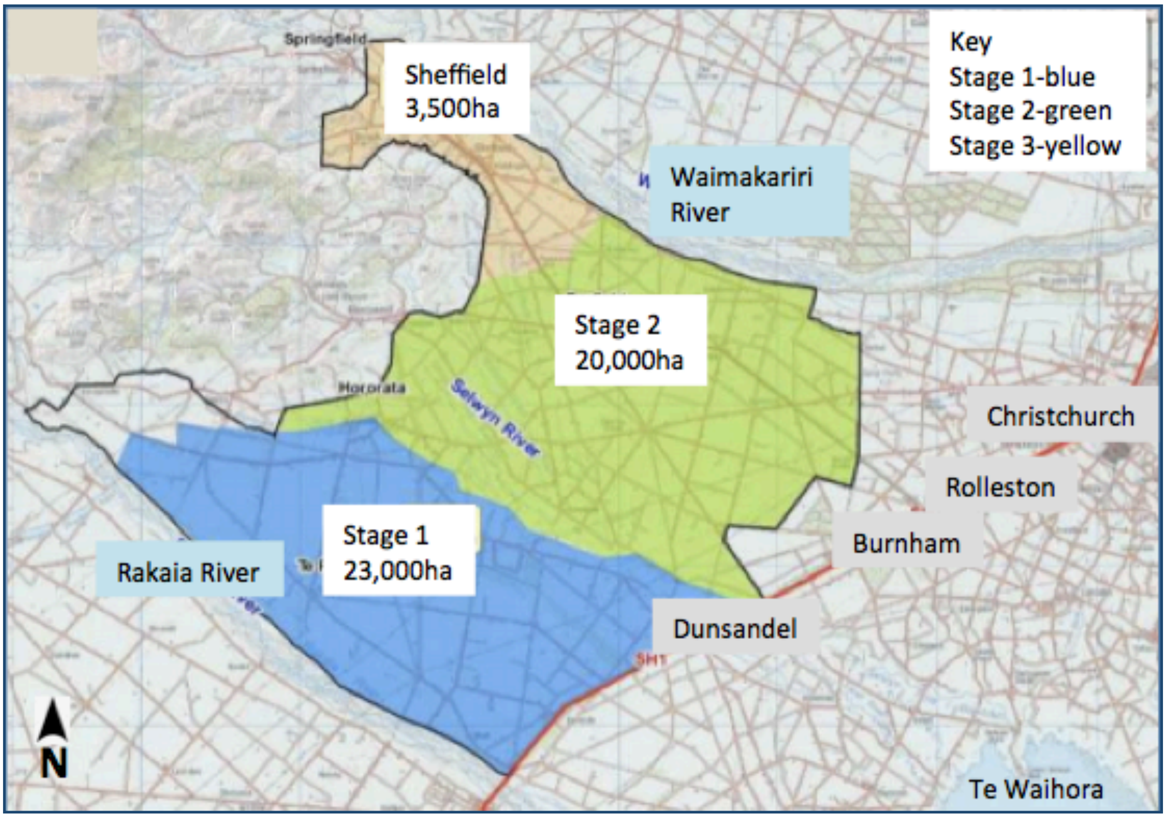


Figure 1-26: CPWL irrigation area showing the three stages of progress (adapted from CPWL, 2017). Map scale approximately 1 cm to 5 km.

1.7 The need for an integrative monitoring programme

Schallenberg et al. (2010) emphasise that unless the lake processes of Te Waihora are well understood, (especially the effects of openings/closures), unintended consequences may occur. The water quality issues of the lake are affected by climate change and sea level rise, changes in the flows of the Rakaia and Waimakariri Rivers due to climate and changing management, overall intensification of catchment land use, initiatives such as CPWL coming online, water augmentation proposals due to more frequent droughts (Pattle, Delamore & Partners, 2015) and increasing population in the Selwyn–Waihora catchment. Monitoring data is required to assess the effect of such changes.

ECan has traditionally done much of the research, monitoring and documentation associated with the management of this area (Figure 1-25) but differing objectives of the many stakeholders, have given rise to various other monitoring and restoration projects, or intervention action plans. Additionally, legislation is evolving, as the collaborative processes continue, emphasising further aspects to be incorporated into the monitoring of these water bodies. Monitoring programmes are limited by the objectives of the organization that initiated them, but integration of these and the sharing of field data of the different networks help to create authenticated robust data. (Borden & Roy, 2015).

The Ministry for the Environment lists Te Waihora as one of its “Clean-Up Projects”. It states “Good decision-making about freshwater management requires community-based judgements supported by scientifically robust technical information and an assessment of economic impacts” (MfE, 2014c). One of the measures to address this is stated as the development of a robust monitoring programme.

During the Review of New Zealand (OECD, 2017), the committee visited Te Waihora/Lake Ellesmere where systems to manage a diversity of freshwater stakeholders were discussed and which may offer peer learning for other countries (“Record”, 2016). This high interest, the complexities of stakeholder interactions in Te Waihora, as well as the new requirements pertaining to catchment land use (e.g., ZIP, Farm Environment Plans, Best Management Practice) and the need to progress lake management to achieve improvement in the lake ecosystem show the need for many new initiatives, one being the development of a robust overarching integrative water quality monitoring system.

1.7.1 Research Aim and Objectives of this research

The aim of this research is to design a robust and integrative water quality monitoring programme to help ensure all future water quality changes to the lake and its tributaries are detected and can therefore be managed appropriately and cost-effectively. This has been required as a part of the overarching monitoring strategy developed by Hughey (2015) and includes both focusing the work of established management agencies, and targeting data collected during teaching and research of both Lincoln University and the University of Canterbury. The developed programme will take account of standard programme monitoring protocols and the specifics of the local conditions related to Te Waihora and will integrate this programme with existing monitoring.

This will be achieved via the following objectives:

1) Identify the key requirements for an overarching, integrative monitoring programme.

2) Develop an effective design.

3) Identify where existing monitoring work cannot contribute to this and recommend methods for gaps to be filled.

Chapter Two – Methods

2.1 Study design

This chapter outlines the methods used to develop a robust long-term overarching monitoring programme for Te Waihora, taking account of current monitoring of the numerous Te Waihora stakeholders. Stakeholder interests and objectives may differ from each other in some instances. This complexity and the high degree of interest in Te Waihora has resulted in many monitoring events (regulatory, interest groups, research, and educational). This has led to the appearance of a well-monitored system, but with gaps and areas that are not being addressed. The methods used to achieve this overarching programme were firstly to document the current and historic water quality monitoring programmes of relevance to Te Waihora, then to design an 'ideal' water quality monitoring programme for the lake. This designed water quality monitoring programme was then compared with existing monitoring programmes (with differing objectives and sites) to identify differences and ways to fill any obvious omissions and gaps. Finally, recommendations were made to integrate existing water quality monitoring programmes with additional monitoring or surveys to achieve a multi-objective integrative system.

Personal contact with stakeholders, as well as online searches and a desktop review were a part of the methodology to compile the list of current (and previous) programmes and surveys. For the development of the 'ideal' monitoring programme, fieldwork was carried out for initial assessments, to identify or confirm specific sites and/or tributaries, to identify any hot spots and confirm the practicability and logistics of the proposed programme.

2.2 Current context of monitoring

An overview of Te Waihora and its catchment has been documented in Chapter 1. This includes a broad history, hydrology, generalised lake use, land use and water use, different types of waterways and their functions and management, the lake opening/closing regime, current and future population estimates and Te Waihora stakeholder interests and objectives. The objectives of stakeholders relevant to Te Waihora were documented primarily from the mission statements and/or the objectives stated by each interest group.

2.2.1 Monitoring within the lower catchment.

The compilation of a record of historic and current water quality monitoring programmes relevant to Te Waihora required contacting all regulatory bodies, local authorities, voluntary and interested parties, and numerous stakeholders.

ECan hold a large amount of water quality data relating to a number of their responsibilities. These include SoE monitoring, investigative surveys and data relating to the consenting process. A resource consent (e.g., to take and use water, or to discharge water or effluent to land), may require a water quality monitoring programme as part of the conditions of the consent. These consent conditions are applicable to some of the stakeholders within the Te Waihora catchment. The Te Waihora catchment encompasses parts of Christchurch City Council (CCC) and Selwyn District Council (SDC) areas and these agencies are required to carry out monitoring for consenting or regulatory purposes. Additionally, several stakeholders have carried out monitoring in the areas relevant to them, to achieve their specific objectives.

A record of known improvement initiatives being undertaken and relevant to Te Waihora was compiled by contacting regulatory bodies, agencies, voluntary and interested parties, professional associations, and interested stakeholders within the catchment. Online searches were carried out. These are shown as a *layer* using Google My Maps (section 2.2.2) to give an overall visual image of the data. Google My Maps is a very simple way to show the spatial relationship between improvement initiatives, monitoring, proximity to waterways and the lake.

2.2.2 Google My Maps.

The historic and current information has been documented in this thesis as well as using Google My Maps to give an overall visual image (as used in Figure 3-1). The use of

Google My Maps enables a simple overall colour-coded picture of current and past monitoring to be shown on the map but can also incorporate a large amount of relevant information and data by using the *pop-up* and *layer* functions.

This easy-to-access system shows information pertaining to each site from a pop-up box at the site (e.g., land use within the tributaries' catchment, photos of monitoring sites) and map layers are used to show catchment activities relevant to Te Waihora (e.g., improvement initiatives). Links to current water quality data and trends at each site can be accessed from the 'pop-up' box also. The link to this is a part of the Waterways Centre website.

2.3 Water quality monitoring programme design

A water quality monitoring programme was designed using the principles of Chapman (1996), Allard (1992) and Bartram and Balance (1996), as outlined in Chapter 1, and taking account of the current regulatory requirements (Tables 2-7 and 2-8) as well as potential future needs.

The natural processes within a water body are documented by Bartram & Balance (1996) and shown in Table 2-1. The selection of the key variables considers water type, natural processes, pressures, specific objectives and impacts (ERR, 2016) of the water quality for the management and restoration information requirements. Elliott and Sorrell (2002) emphasise measuring loads as an important tool for water quality management.

The unique requirements of Te Waihora as an ICOLL on the east coast of the South Island are also an integral part of the design. As previously noted, all ICOLLs have their own unique attributes requiring a very local and specific structure to capture the characteristics of each. These specifics have been outlined in Chapter 1 and are taken account of in the design criteria. Meredith et al. (2003) emphasise the relationship of aquatic communities to anthropogenic land use and the importance of the wide range of possible environmental factors in programme design (Table 2-2). These factors were considered in the development of the design for water quality.

Table 2-1: Natural processes affecting water quality (Bartram & Balance, 1996).

Process type	Major process within water body	Water body
Hydrological	dilution	all water bodies
	evaporation	surface water
	percolation & leaching	groundwater
	suspension & settling	surface water
Physical	gas exchange with atmosphere	mostly rivers & lakes
	volatilisation	mostly rivers & lakes
	adsorption/desorption	all water bodies
	heating & cooling	mostly rivers & lakes
	diffusion	
Chemical	photodegradation	
	acid-base reactions	all water bodies
	redox reactions	all water bodies
	dissolution of particles	all water bodies
	ionic exchange	groundwaters
Biological	primary production	surface waters
	microbial die-off & growth	all water bodies
	decomposition of organic matter	mostly rivers & lakes
	bioaccumulation	mostly rivers & lakes
	biomagnification	mostly rivers & lakes

Monitoring methodology began with setting some basic objectives for the programme to support the design of a robust, simple but integrative system. Chapman (1996) sets out some typical objectives (Table 2-3). This programme utilizes and builds upon them. Hydrological information is key to much of the behaviour of Te Waihora. Level C of Table 2-4 is the optimal information for Te Waihora to detect inflow flux and floods, drought, lake openings and water levels in real time. This is available for some of the tributaries and relationships are established for others. In particular, the future use of data and the *why* component of data collection, must be taken into account. Monitoring site locations should be clearly georeferenced. Due to the rapid change in legislation and its flow-on effects, modelling data may be an additional requirement for the legislation changes. These postulated scenarios require real-time confirmation for relevant and robust management.

Table 2-2: Five major classes of environmental stressors that affect aquatic biota in rivers (adapted from Karr et al., 1986).

Ecological impact of human induced alterations	
Energy source	type, amount and particle size of organic material entering a stream from the riparian zone, versus primary production in the stream
	seasonal pattern of available energy
Water quality	temperature
	turbidity
	dissolved oxygen
	nutrients (primarily N & P)
	organic and inorganic chemicals, natural and synthetic
	heavy metals and toxic substances
	pH
Habitat quality	substrate type
	water depth and current velocity
	spawning nursery and hiding places
	diversity (pools, riffles, woody debris)
Flow regime	water volume
	temporal distribution of flood and low flows
Biotic interactions	competition
	predation
	disease, parasites

Table 2-3: Typical objectives of water quality assessment (Chapman, 1996).

Type of operation	Major focus of water quality assessment
Multi-purpose monitoring	Space and time distribution of water quality in general
Trend monitoring	Long-term evaluation of pollution (concentration and load)
Basic survey	Spatial distribution of major survey problems
Operational survey	Water quality for specific uses (parameters)
Background survey	Background levels for natural processes
Preliminary survey	Inventory of pollutants & their spatial & temporal variability Prior to design
Emergency surveys	Rapid situation assessment following a catastrophe event
Impact surveys	Sampling limited in time and space, generally focusing on a few variables
Modelling survey	Intensive assessment limited in time, space & variables
Early warning surveillance	At critical locations, continuous & sensitive measurements

Table 2-4: Hydrological information required for water quality assessment (Chapman, 1996).

Level	Rivers	Lakes/Reservoirs	Groundwaters
A	River level at sampling	Lake level at sampling	Piezometric level
B	River discharge at sampling	Lake level between sampling	Piezo level between sampling
C	Continuous river discharge	Tributary discharge & lake water budget	Full knowledge of dynamics
Levels A,B,C are increasing orders of assessment programme complexity			

Methodology with regard to the design of the programme was based on an adapted flow-chart of the Global Environment Monitoring System (GEMS; Allard, 1992) shown in Figure 2-1 and related to each aspect of the current requirements and legislation for Te Waihora.

The application of this diagram for Te Waihora was to relate Item A to the present and future water use in the context of the four well-beings (environmental, social, cultural and economic). Item B was to document the influencing factors of intensification of land use and climate change. Potential water sources (Item C) are rainfall, seawater, inflow from tributaries, water races, drains and potential augmentation. Water quality data (Item D) is stored by MfE, ECan, NIWA, Universities and other stakeholders. Item E is found in Chapter 4 as maps, graphs and photos, while Item F encompasses the main and secondary objectives of this monitoring programme. The PSR system is used for Item G with an overview of the criteria and weighting of sites to establish required information and planning (Items H and I). Chapter 5 defines Items J, K, L, M and N to finalise sites through research and surveys and documenting regular monitoring programme reviews.

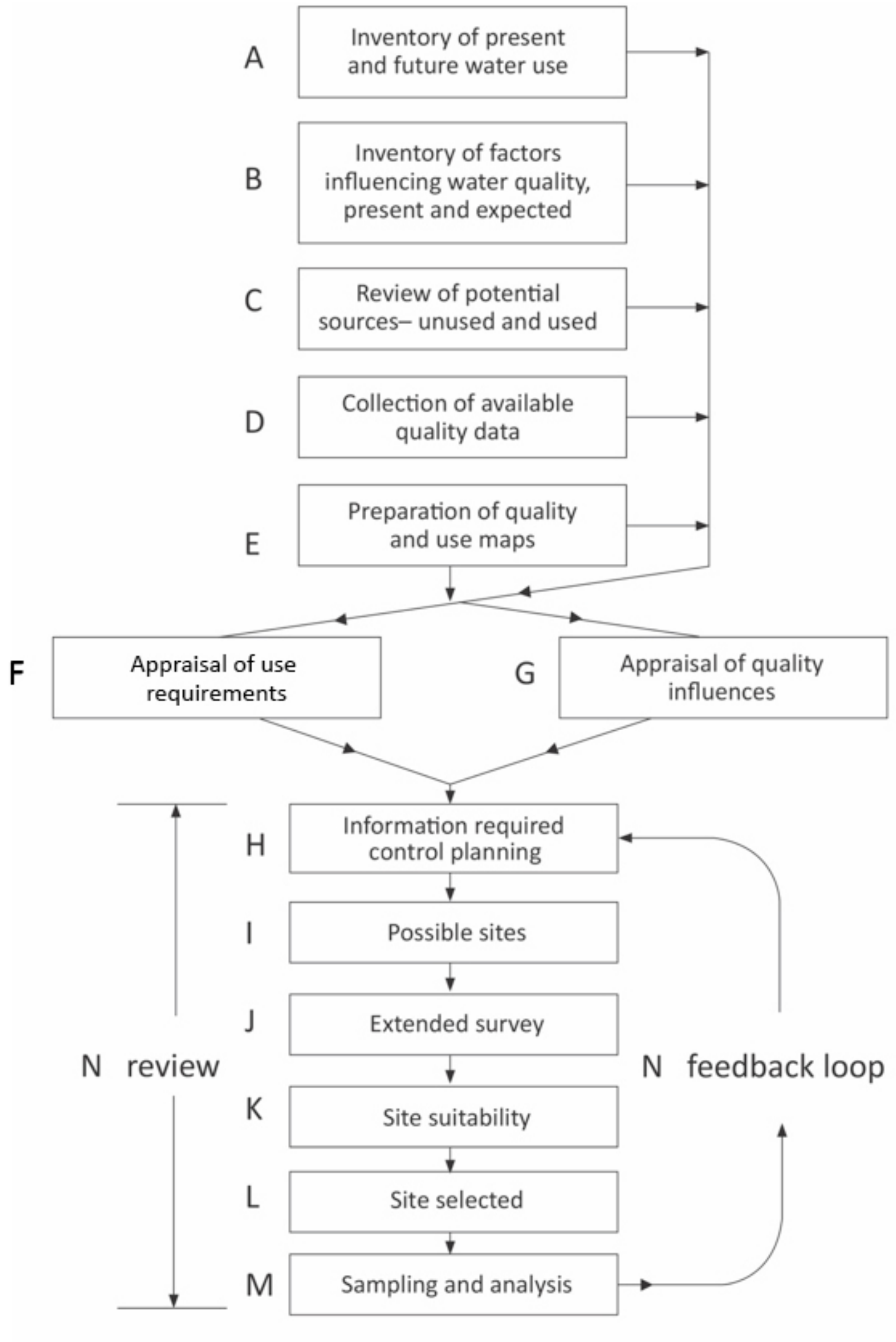


Figure 2-1: Diagram for selection of water sampling sites (adapted from GEMS; Allard, 1992).

2.3.1 Use of criteria for selection of sites

The selection of sites for this design has taken account of the above principles and incorporated them (with more specific and local requirements for Te Waihora) into a set of criteria. These criteria were then weighted against each other using a numbered system (1 to 5) relating the importance of the attribute (e.g., percentage of total inflow volume to Te Waihora) or as pass/fail. The weighted results may need additional surveys or research to confirm aspects of the choices (e.g., recommendations made regarding the monitoring programme in Chapter 5).

The main tributaries flowing into Te Waihora are shown in Figure 1-24, however there are many smaller ephemeral drains and streams. All streams, drains and rivers with significant water were considered, but due to the climatic conditions at the time (intensive drought for three years) many drains and smaller streams had insufficient or no water.

Criteria for site selection—tributaries

The actual tributary and the location of its site were chosen according to the criteria below. These criteria were used to determine which tributaries to include in the programme followed by the actual site on the tributary, often known as macrolocations and microlocations (Strobl & Robillard, 2007).

Criterion 1: Stream type and spatial position of tributary (spatial representativeness)

There are over 40 streams, rivers and drains in the lower Te Waihora catchment. The NRRP Chapter 4 identifies river type and spatial resolution (to select representative types and spatial positions of streams for management) as an important aspect of monitoring.

The NPS-FM (2014) states that sites for monitoring purposes, must be representative of the freshwater management *unit* (MfE, 2014). Figure 1-11 shows the general water movements in the Te Waihora catchment, but representativeness is inherently complex. The water quality of the Te Waihora tributaries falls into three main *categories*. Some units in this area will be simply rain-fed within their catchment, run-off and associated catchment land use, for example, Banks Peninsula streams. Other units require an understanding of the relationship between the first aquifer groundwater and the stream, if completely spring-fed. Other lower catchment streams are spring-fed, but also receive water from water races (either Waimakariri or Rakaia river water).

The interpretation of water quality reports requires this understanding to achieve correct management, as the parameters in a water quality report for a lowland site, may be only partially representative of that immediate catchment area. This water management at a local level is emphasised as a key aspect by the CWMS (ECan, 2015) and Kelly et al. (2014). Streams are categorized (for modelling requirements) by Clark (2011) as influenced by the Waimakariri River, Rakaia River or from the Selwyn River hills-fed streams. Bias due to the selection of streams with most pollution potential, has been noted as giving an erroneous overall perception of catchments (OECD, 2017). To address these aspects, the tributaries were selected as representative of (a) Banks Peninsula (note some Banks Peninsula valley streams are tributaries of the Halswell River), (b) western tributaries (both Waimakariri River influence and Rakaia River influence–spring-fed lowland streams), and (c) more southern tributaries (Rakaia River influence–spring-fed lowland streams). These criteria are very similar to the Clark (2011) categories.

Criterion 2: Significant contribution to the total inflow and load into the lake

To achieve the most cost-effective monitoring programme, the fundamental assumption was to ensure the number of monitoring sites were representative of and in proportion to (a) the size of the catchment area and (b) the loads of sediment and nutrients being discharged into the lake (tributary flow and load; Elliott & Sorrell, 2002). Specific catchment areas are complex (Clark, 2011) for many reasons; for example, the ephemeral nature of many streams, the underlying geology and structure of the plains, and the number of small ephemeral drains flowing directly into the lake. Additionally, the ratio of flows and loads into Te Waihora are changing, as well as the perception of the main tributaries. Table 2-5 is a compilation of median tributary flow data from 1991 to 2007 and 2015 to 2017. The shaded column (six months from October 2016 to March 2017) has been included to emphasise the different percentage inflows (and tributary ratios) during different climatic conditions. Flood conditions would also be expected to significantly change both the percentage inflow and the ratio.

The Irwell River was historically considered to have a significant inflow, but currently is frequently dry. Clark (2011) states that the Selwyn River, Harts Creek, Irwell River, L II

River and Halswell River are a good representation of the catchment; however, flows in general have decreased by 15% to 20% (ECan, 2015) and ratios changed. This fundamental assumption of the size of the tributary catchment as a criterion is affected by the ephemeral nature of some tributaries and the large numbers (mainly drains) with very small flows or no water at all, showing that the flowing stream length (with consistent base flow) may be a more valid factor in site selection. There are two significant areas (south of the Selwyn River and between the L II and the Halswell Rivers) that have no continuously flowing reach but are predominantly ephemeral drains that flow only in times of higher rainfall. Again, emphasis is on the possibility of changing climatic conditions.

Criterion 3: Point-source pollution locations

The pressure that towns/cities and anthropogenic activities exert on water quality will affect site selection regarding run-off, potential point-source pollution (industry, septic tanks, waste water, petrol stations, landfill areas), discharge to land consents or other urban/industrial activities. This may initially be point-source contamination, but will result in diffuse pollution as it discharges into Te Waihora. The main towns are shown in Figure 1-24. A number of surveys and studies have been carried out by different stakeholders, for example, SDC when a sewerage scheme was constructed in Leeston or new drainage systems provided for Lincoln, but consistent localized monitoring has not been continued for many of these. This catchment is New Zealand's second fastest growing county (SDC, 2016b). *The Lake Managers Handbook* (Elliott & Sorrell, 2002) notes that nationally, point-source inputs are considerably less significant than diffuse pollution. This is currently the situation for Te Waihora but longer term monitoring of point sources is still considered to be valid (Bartram and Balance, 1996).

Table 2-5: Compiled data showing median tributary flow and percentage of total inflow to Te Waihora (ECan data, 2016; Clausen & Horrell, 2007; NIWA, 2015)

	data pre 2007				**data after 2007**				**interest only**	
	Clausen/Horrell (1991-2007)		**ECan & NIWA (1994-2005)**		**ECan/WTW to 2015**		**Ecan (2016)**		**ECan 2016-17(6mths)**	
	Flow (m3/s)	**% inflow**	**Flow (m3/s)**	**% inflow**	**Flow (m3/s)**	**% inflow**	**Flow (m3/s)**	**% inflow**	**Flow (m3/s)**	% inflow
Southern tributaries										
Waikekewai Creek	0.187	1.8					0.03*a*	0.4	0.02*a*	0.5
Ludeman Drain	0.091	0.9								
Hawkins drain	0.019									
Lambies & Mansons	0.093									
Western tributaries										
Harts Creek	1.483	14.4	1.49	13.8	1.5	14	1.4	17.7	0.9	21.2
Nairns Drain	0.067									
Lancasters Drain	0.059									
Tramway Res Drain	0.135	1.3					0.05*a*	0.6		
Doyleston Drain	0.173	1.7	0.19	1.8	0.2	2			0.02	0.5
Hurfords Drain	0.003									
Boggy Creek	0.227	2.2	0.19	1.8	0.2	2	0.03*a*	0.4	0.03*a*	0.7
Hanmer Rd Drain	0.28		0.33	3.1	0.3	3				
Irwell River	0.649	6.3	0.63	5.8	0.6	3			0	
Stephens Drain	0.005									
McLaughlins Drain	0.031									
Kendalls Drain	0.004									
Coes Drain	0.035									
Selwyn River	2.89	28.1	2.74	25.4	3.1	29	2.3	29.1	0.35	8.3
Silverstream							0.3*a*			
L II River	1.941	18.9	1.94	18	2.3	21	2.2	27.8	1.8	42.5
Greenpark Main Drain	0.005									
Clarks Rd Drain	0.001									
Osbornes Drain	0.002									
Halswell River	1.025	10	1.09	10.1	0.9	8	0.8	10.1	0.58	13.7
McQueens Stream	0.029	0.3								
Banks Peninsula Tributaries										
Nutts Cut	0.01									
Greylees Drain	0.024									
Coops Drain	0.01									
Kaituna River	0.568	5.5	0.38	3.5	0.6	1	0.6	7.6	0.54	12.7
Birdlings Drain	0.056									
Turrells Drain	0.008									
Prices Valley	0.184	1.8								
small tributaries			1.79	16.6	0.6		0.2*b*		0	
Total	10.29		10.77		10.2		7.91		4.24 (6 mths)	

a-spot gauging
b- estimate only

Criterion 4: Diffuse pollution and land-use effects

Intensification of land use, particularly the current increases in dairying, within the Selwyn–Waihora catchment has been one of the current major diffuse pollution concerns. Changes in water quality due to diffuse pollution or improvement initiatives, need to be captured accurately. Site selection for this aspect is inherently difficult. Many improvement initiatives have been initiated or completed, for example, stream fencing is to be 100% complete by May 2017 and riparian planting is continuing, decreasing both sediment and nutrient run-off into streams. These activities are difficult to quantify. Site selection for Te Waihora will show catchment-wide increase or decrease.

The main nutrient increase affecting water quality in the tributaries of Te Waihora is postulated to be due to the leaching of nitrogen into the aquifers and thence into the springs feeding the tributaries, as well as some direct aquifer flow into Te Waihora (ECan, 2013). For management purposes, it may be necessary to carry out a survey at, or near, the source/spring of a tributary to establish the water quality of the groundwater flowing into the stream (not attributed to neighbouring land use). Catchment-wide diffuse pollution and emerging contaminants are monitored at the bottom of the catchment before entering Te Waihora.

Criterion 5: Compliance with the RMA (1991), NPS-FM (2014) and other regulatory requirements for monitoring is mandatory. Site selection will take these into account as well as any other regulatory requirements. Sites should also be suitable for the requirements of cultural assessment (Tipa, 2006).

Criterion 6: Historical data

Historical data availability is highly preferable (and highly weighted) for both state and trend analysis, but monitoring sites reported as "*no water*" may have equal relevance (or weight) for catchment and lake management purposes. Rainfall, water quantity and water quality require appraisal for site selection, interpretation and management. From this perspective, site selection should take account of continuous historical data where possible.

Criterion 7: Optimal number of sites

The number of tributaries chosen must be weighted against the previous criteria with regard to representativeness or any obvious pollution, as well as the overriding aspect of monitoring, testing and reporting cost. Beca (2012) agree with others that a smaller number of robust sites and robust parameters lead to more effective monitoring. The current routine budgeted monitoring (ECan) use 13 sites. The potential number to efficiently document this lake was planned to be between 10 and 12 sites.

Additional criteria to select the site on the tributary were:

Criterion 8: Fresh water/lake water interface

This interface is influenced by the opening and closing of the lake, lake water level, prevailing winds and tributary flow. To establish where the most downstream site above the fresh water/lake water interface occurs (considering lake level, wind and flow), a series of conductivity measurements were carried out along the waterway, at differing lake levels and in differing climatic conditions. Sites were then selected to be upstream of this interface (but as close as practical to the lake to capture all possible inflows and local catchment effects), to ensure the water quality reflects the lake inflow.

Criterion 9: Land ownership for sampling and access

Land ownership to allow access for sampling is important for the longevity of the monitoring programme (Table 4-1b). Public (including DOC, government or district-owned land) ownership is essential as although private ownership may be suitable currently, with the landowner's permission, there is the possibility of land being sold, at which time continuity of data (gained at a considerable cost) could be lost. This would severely affect management decisions and make the monitoring programme less robust.

Criterion 10: Practical access and safety

Site access is highly important for safety reasons. Cost, the ability to adequately collect samples, carry out gauging and on-site analyses are also important criteria for site selection. Transportation time to the laboratory must be within acceptable limits. The site must be safe regarding traffic and vehicle parking.

Criteria for site selection—lake sites

The principle objective for monitoring a lake is to detect the state and change in water quality over time. This large (20,000ha) and shallow unstratified ICOLL (average depth 1.2 m) has its own specific and unique set of issues. The choice of monitoring sites within Te Waihora is dependent on the objective, which is to provide a robust database, to identify state and trends, address any specific attributes of Te Waihora, to detect any adverse pollutants that will affect the environmental state and ecosystems and to enable the trophic level of the lake to be determined.

Criterion 1: Representativeness

Te Waihora has differing water quality in different areas of the lake, resulting from local inflows (including sea water). The choice of sites must be representative of the specific area of the lake to show state and trends in relationship to contiguous habitats.

The sites in the lake must be able to detect the presence of all pollution but especially traces of any emerging contaminants, or any parameters, which are important to Te Waihora as an ICOLL with significant wetlands and unique habitat areas (e.g., salinity, heavy metals or endocrine-changing contaminants). Local issues or concerns on a stream may dictate additional or changed sites, frequencies or parameters.

Criterion 2: Practical access and safety

To ensure longevity, site selection must take all safety aspects into account, as well as ensuring good sampling techniques and sample integrity are mandatory. Hazard and risk assessment must be carefully documented in all lake water sampling plans.

Criterion 3: Historical data

Sites with long monitoring data records are preferable to include for continuity of state and trends, unless an extremely valid reason to change is clear. However, Strobl and Robillard (2007) note that fear of redesigning a water quality monitoring programme could result in expensive but useless data if not routinely reviewed. This aspect will be considered as part of the routine review.

Te Waihora has five ECan-monitored sites predominantly in the western part, with data dating back to 1983 and these sites will be strongly considered for this monitoring programme because any site changes at this time may negate valuable historical data.

Criterion 4: Compliance with NPS-FM (2014) and all other local regulatory requirements (e.g., CLWRP). Te Waihora is a coastal lagoon/ICOLL and the “sink” for the by-products of human, industrial, animal and all land-use activities within the catchment. These facts should be uppermost in the routine monitoring site choice design, as emphasised by Bartram and Rees (2000).

2.3.2 Use of criteria for selection of parameters

As stated, Te Waihora as a sink at the end of an intensively farmed catchment, an ICOLL and a diverse aquatic habitat, requires specific parameters to detect and monitor the ecosystem health for the protection of indigenous species (Strobl & Robillard, 2007). Historically, sediment has long been recognized as a major problem for lowland ecosystems (Ballantine, Hughes, & Davies-Colley, 2014) and this aspect is one of the major problems for Te Waihora.

New nutrient inputs into Te Waihora (as opposed to recycling the nutrients within the lake itself) come from three main sources: tributary inputs, groundwater seepage and atmospheric deposition (Renwick et al., 2010). The tributary inputs contain the greatest percentage of new nutrients as well as sediment. In-lake changes in water quality are also shown to be important by Schallenberg et al., (2010), where it is noted that a substantial microbial loss of N (within the lake) lowers the ratio of N to P and concentration, in comparison to the loading rates. Additionally, recent research shows that the in-lake nutrient processes affect nutrient availability and algal bloom frequency (Schallenberg, 2017). These findings will influence lake management and confirm the inclusion of both N and P monitoring as well as the different forms of suspended sediment in the lake tributaries and within the lake itself. These issues should be revisited at monitoring programme review times. 'Parameters' is used to refer to water quality determinands, attributes or variables.

The criteria used to select appropriate parameters must reflect the pressures specific to this region (Kelly et al., 2014), possible pollution and the regulatory requirements. The parameters selected for monitoring, management or analysis must be robust. There are many systems that can be applied to confirm 'robustness' in the context of water quality. Two of the common systems are SMART (Specific, Measurable, Achievable, Relevant, Time-bound; Beca, 2012) or CREAM (Clear, Relevant, Economic, Adequate, Monitorable; Kusek & Rist, 2004). MfE has initiated research into the effectiveness of the RMA (Beca, 2012) where SMART is a requirement for their assessment of indicators (and parameters). The selection of parameters for this design encompasses these aspects (integrated within the specific criteria). Common water quality parameters are shown in Table 2-6. The choice for monitoring will be a subset of these; or may add specific further parameters reflecting local conditions or concerns.

Table 2-6: Common water quality variables (Bartram & Balance, 1996).

	Rivers	Lakes and Reservoirs	Groundwater
General water quality			
water discharge/level	X	X	X
total suspended solids	X		
temperature	X	X	X
pH	X	X	X
electrical conductivity	X	X	X
dissolved oxygen	X	X	X
transparency		X	
Dissolved salts			
calcium	X	X	X
magnesium	X	X	X
sodium	X	X	X
potassium	X	X	X
chloride	X	X	X
fluoride			X
sulfate	X	X	X
alkalinity	X	X	X
Nutrients			
nitrate plus nitrite	X	X	X
ammonia	X	X	X
total phosphorus, dissolved	X	X	
total phosphorus, particulate	X	X	X
total phosphorus, unfiltered	X	X	
silica, reactive	X	X	
Organic matter			
chorophyll *a*	X	X	

The routinely measured parameters for the National Rivers Water Quality Monitoring (NRWQM) are: conductivity, pH, temperature, DO, visual clarity, turbidity, coloured dissolved organic matter, faecal indicator bacteria and different forms of nitrogen and phosphorus (NIWA, 2017b). Associated benthic biological monitoring comprises monthly visual assessment of periphyton and annual sampling for macroinvertebrates.

The National Environmental Monitoring and Reporting (NEMaR) project: Freshwater Monitoring Protocols and Quality Assurance (QA) states 11 "core variables" for lakes (Table 2-7), and for rivers (Table 2-8) and it also suggests conductivity as a measure of ionic content for rivers and lakes (Davies-Colley et al., 2012). Effective lake management requires that parameters show the state and trends of the water body, as well as allow for their use in future modelling (MfE, 2017a). Health for human recreation is not a part of this thesis. The 2017 amendment of the NPS-FM also requires DIN and DRP to be measured in rivers. Compulsory attributes for lakes are TN, TP and Chlorophyll *a* (MfE, 2018). Beca, (2012) recommend parameters comply with the SMART 'criteria'.

A facet of importance to Te Waihora is the effect of wind. As previously noted, due to the large area and degree of shallowness, sediment disturbance by wind-induced currents should be considered (Burns et al., 2000). Also, much work has been carried out on the salinity of Te Waihora (Spigel, 2009). This is complex, and modelling has been difficult. The artificial opening procedure, rough sea inflow and evaporation all affect salinity within the lake. The choice of parameters to best show environmental trends and state is a combination of the weighting of the criteria in Table 2-7 and Table 2-8, to produce a robust, long-term, cost-effective practical programme. These data may be supported by additional specific surveys and routine revisions.

Table 2-7: Minimal set of water quality variables (core variables) for lakes as recommended for the NEMaR (Davies-Colley et al., 2012).

Lake water quality variables/index	Needed for?
Total nitrogen (TN)	Trophic level index (TLI)
Total phosphorus (TP)	Trophic level index (TLI)
Chlorophyl a	Trophic level index (TLI) Index phytoplankton biomass
* Secchi depth	TLI4* Optical characterisation
Temperature profile	Thermal stratification (climate change)
DO profile	Hypolimnetic de-oxygenation
Lake SPI index (based on submerged plant survey)	Integrating index of lake condition
*Secchi depth should still be measured for general optical characterisation even if not used in TLI4 calculation	

Table 2-8: Minimal set of water quality variables (core variables) for rivers as recommended for the NEMaR (Davies-Colley et al., 2012).

River water quality (WQ) variable	Needed for?
Discharge (flow 'stamping')	State-of-flow for WQ interpretation & load calculation
Temperature	Thermal conditions (climate change)
Dissolved oxygen (DO)	Oxygen conditions for aquatic life
Black disc visibility	Measure of visual clarity (aquatic life & human use)
*Total suspended solids (TSS)	Relevant to sedimentation effects & sediment loads
Ammoniacal nitrogen	Nutrient (immediately bioavailable), toxic (as NH_3)
Oxidised nitrogen (NOx)	Nutrient (immediately bioavailable), toxic
Total nitrogen (TN)	Nutrient
DRP	Nutrient (immediately bioavailable)
Total phosphorus (TP)	Nutrient
E. Coli	Indicator of faecal microbial pollution
* TSS & visibility are inversely correlated so there is a degree of redundancy in monitoring both (Davies-Colley & Smith, 2001)	

Criteria for parameter selection

Criterion 1: Regulatory requirements

All regulatory requirements must be included in the choice of parameters.

Criterion 2: Use of data

This monitoring programme is designed to be robust and integrative and useful to a range of stakeholders. Effective lake management requires managers to use data to show the overall climatic conditions at the time, state and trends of the water body, and also data for future environmental modelling scenarios (although the latter may require additional specific parameters or surveys). The parameters must be adequate for the regional issues, planning and management needs.

Criterion 3: Specific pressures on the lake environment

Knowledge of the local pressures (environmental stressors) associated with the lake and its catchment are key aspects for a monitoring programme (Kelly et al., 2014) and are reflected in the choice of parameters. The choice of one parameter over another, or whether an *indicator* is more cost-effective to achieve the desired data is considered. Local climatic conditions (as previously noted) are an important aspect of Te Waihora for parameter interpretation and management.

Assuming point-source pollution is well managed, one of the key pollutant sources for the Te Waihora catchment is diffuse pollution from pastoral farming. This includes (a) nutrients from livestock wastes, fertilizer application, eroded sediment; (b) microbial contamination from livestock faeces; (c) sediment (NIWA, 2017a). Phosphorus (possibly associated with sediment) has traditionally been considered a growth-limiting nutrient and driver of eutrophication (Conley et al., 2009), but in Te Waihora, both nitrogen and phosphorus can be the limiting nutrients during different conditions within the lake (Ford et al., 2017). As noted by ECan (2002), the tributaries and the lake have very different ecological dynamics (e.g., ratios and predominant species change from one water body to the other).

Criterion 4: Historical data

Historical data is essential to show robust trends; however, unlike site selection, it may be possible to determine a valid relationship between different parameters, if a current or future change in parameter is desirable (e.g., the relationship between TSS, clarity and turbidity). Care must be taken in any redesign of water quality monitoring parameters as there is the potential to put at risk much very valuable historical data, especially for trend analysis (Davies-Colley et al., 2012).

Criterion 5: Interdependence of parameters

Many physical, chemical, bacterial and ecological parameters are interdependent. Temperature and pH will affect many of the commonly monitored parameters (e.g., temperature on DO). Schallenberg et.al. (2010) describe the relative importance of N and P in the lake at different salinities and oxygen concentrations. The effect of the status of the lake (open/closed) will affect parameters, but Schallenberg et al. note that this only weakly affects N and P. However, McCready and Paine (2013) found a relationship between general water quality (TLI) and lake openings. Underwater light limitations and nutrient availability may also be interdependent (MacKenzie, 2016). Increased (resuspended) sediment due to wind-induced turbulence is also a critical parameter for Te Waihora. A robust programme (for longevity) should be designed to take account of this interdependence of parameters. These interdependencies may be relevant to site selection also.

Criterion 6: Cost-effectiveness

The longevity of a robust monitoring programme often depends upon the cost-effectiveness of the design. As stated under section 2.3.2 a smaller number of robust relevant parameters will enable better use of data (Beca, 2012). These may be interspersed with specific surveys (as required).

2.3.3 Use of criteria for selection of sampling frequency

Temporal trend analysis requires regular data collection (Kelly et al., 2014). The establishment of the state of a water body at a single point in time is relatively straightforward; however, to establish changes and trends, a consistent set of parameters around the pressures on the catchment or area must be understood. Spring-fed lowland streams (Te Waihora lower catchment streams) show high variability both spatially and temporally (Stevenson et al., 2010). River type, has in some areas, been the criterion for frequency of monitoring, but following the 2013 review, Kelly et al. (2014) stated that this bias should not be present. Monthly monitoring at all selected sites is the frequency of choice (Kelly et al., 2014). One aspect of relevance to frequency, which has not been addressed in previous monitoring, is flood flows and loads. This is of importance to Te Waihora as sediment and nutrients are the main aspects of concern.

Criteria for frequency selection

Criterion 1: Regulatory requirements.

Regulatory requirements of many parameters or sites will dictate the frequency required. NPS-FM (2014) recommends sampling visits to be monthly for routine environmental monitoring.

Criterion 2: Use of data

The information sought and the intended use of the data collected will indicate the frequency. The magnitude of the trends to be detected and the optimal frequency to achieve this may be different for each sub-objective. Ideally, we need to standardize frequency across sites as much as possible.

Criterion 3: Flow and load

Documenting flow and tributary loads calculated from parameters measured during the typical base flow of tributaries is a straightforward exercise. However, measurement during increased flows (rainfall and flooding) requires a more complex approach. This is an area to be addressed for Te Waihora. Flood loads add a major component of sediment to the lake (Larned & Schallenberg, 2006). Dissolved constituents in the water may either increase or decrease during floods (Hoare & Rowe, 1992). Hysteresis may occur (concentrations decline slower than they increase), an example being for TP during a flood. This will significantly affect the load into the receiving waters. A detailed survey/study will be required to establish the most cost-effective method to document flood loads, and determine best site as well as frequency. Current recorder readings could be used to trigger sediment sampling in chosen streams or drains.

Criterion 4: Status of the ICOLL (open/closed)

Te Waihora is a shallow ICOLL and as such, the act of opening or closing the lake has a significant impact upon some of the data being monitored, as does the strength of the wind and climatic conditions. The lake's open/closed status and climatic conditions should be documented on all lake reports to enable correct report interpretation. Frequency of sampling for routine data collection is decided by the water quality regulations, but if a particular trend or pattern (in relation to the open/closed status) is found, the frequency of sampling may be weighted towards the lake status as well as the regular time of monitoring. It may require a separate survey to be carried out.

Criterion 5: Point-source pollution

Point-source pollution of significance may have a variable dispersion time (e.g., dairy effluent at certain times of the year, or systematic discharge time for factories). Report reviews and analysis may dictate specific research or surveys to be carried out.

Criterion 6: Cost-effectiveness and longevity.

For routine sampling, monthly is the required time. Some parameters will give greater information from very frequent sampling, or a survey, while others will require longer time frames between sampling to gain the correct information. Each situation will need specific frequencies to achieve their specific objectives. Again, for routine monitoring, a simple, relevant, practical monitoring programme will have greater longevity and be more robust than the monitoring of many parameters for non-defined reasons or objectives.

2.3.4 Locating the fresh water/lake water interface

Te Waihora is a shallow lake at the bottom of a large catchment. The optimum monitoring sites regarding the interface between the fresh water and lake water were established by carrying out a conductivity survey. All tributaries with flowing reaches were surveyed but several had very little flow or were stagnant pools.

An Orion Star A329 meter was used and the standard method carried out for conductivity measurements (method 2510B in APHA, 2015). The meter was calibrated with the appropriate standards before each series of measurements and checked with one standard between samples. Conductivity is temperature dependent.

The conductivity survey for each tributary involved initial measurements (consecutively on the same day for each tributary) beginning at the lake discharge point (if practically possible) and taking conductivity readings upstream until a site was found where there was no influence from the lake water, that is, conductivity readings did not change by +/- 10 µS/cm. This site (and significant adjacent ones if necessary) was then monitored in different climatic conditions—differing lake levels, lake open/closed high winds from relevant directions and tributary flows. 2016 was the third year with summer drought conditions, resulting in measurements that reflect the drought situation where lake water could have a more significant influence than in conditions of high tributary flow. This may be of benefit to the survey as the situation documented more extreme results than if the tributaries were flowing normally (the interface would be closer to the discharge point).

Conductivity sites for each tributary were numbered numerically beginning (where possible) at the discharge point (e.g., 0, 1, 2). The monitoring site meeting the monitoring programme criteria was then labelled Monitoring Site X (MSX).

The readings were recorded in µS/cm.

2.3.5 Quality control

To ensure the robustness and reliability of a monitoring programme, quality control (QC) is an essential part of every aspect of the programme, from design, data collection, sample integrity, analysis, reporting and interpretation. A standard methodology for each part of the programme ensures the resulting data is accurate and robust, and is fundamental to robust water quality management.

A National Environmental Monitoring Standard for Water Quality has recently been written and is available in draft form (NEMS, 2017a and NEMS, 2017b). It is essential to use standardised methodology for all routine sampling and laboratory analysis with regular national inter-laboratory participation. Comparisons between different monitoring programmes are essential for results to achieve the desired robustness. A monitoring programme should also have a standardized system for spatial and temporal sample collecting, data recording and storage. Adherence to the new NEMS protocols in all areas, will ensure robustness in this monitoring programme. Trend interpretation and the methodology used for analysis is another important part of QC, as stated by Hoare and Rowe (1992). A warning from their study was that phosphorus and nitrogen showed inconsistencies due to the analysis methodology at that time.

Chapter Three – Results

Analysis of current monitoring and its context

Under the RMA, regulatory monitoring is generally carried out in two ways: State of the Environment Reporting (SER) and compliance monitoring (MfE, 2014a). Both are undertaken in the Te Waihora catchment. Additionally, other stakeholders have carried out their own monitoring programmes for specific monitoring objectives.

3.1 ECan monitoring

ECan is the primary regulatory body and carries out regular water quality monitoring programmes within this area. It focuses on the cumulative rather than local/small-scale effects. The NRRP requires ECan to monitor the effects of land use and discharges on surface water quality and to monitor the health of aquatic ecosystems (Stevenson, Wilkes, & Hayward, 2010). The NRRP is the statutory document which directs how ECan manages the natural resources of Canterbury, but is systematically being replaced by the Canterbury Land and Water Regional Plan as the current collaborative processes within the catchment proceed (Kelly et al., 2014). Table 3-1 and Figure 3-1 show the current monitoring programmes for Te Waihora water quality and ecology, carried out by ECan within Te Waihora and in the lower catchment area.

The parameters routinely tested include *E. coli*, pH, electrical conductivity, DO in mg/L and % saturation, temperature, black disc, turbidity, TSS, NO_3-N, NO_2-N, NH_4-N, TN, DRP and TP.

ECan also holds a large amount of water quality data relating to investigative surveys as well as data relating to the consenting processes. A resource consent (for example to take and use water, or to discharge water or effluent to land) may require a water quality monitoring programme as part of the conditions of the consent. A current consent is Central Plains Water Ltd (CPWL) which is required to carry out an extensive monitoring programme as a part of their consent. These consent conditions are applicable to many water users/stakeholders within the Te Waihora catchment.

Table 3-1: ECan water quality and ecology monitoring within the lake and lower catchment of Te Waihora, 2015 (compiled from Ecan data, 2016).

Lake water quality				
Site ID	Site name	Frequency	Easting	Northing
SQ30954	Lake Ellesmere - Mid-Lake	monthly	1556068	5151907
SQ30955	Lake Ellesmere - Off Selwyn River Mouth	monthly	1554459	5155719
SQ30956	Lake Ellesmere - At Taumutu	monthly	1550578	5145424
SQ30953	Lake Ellesmere - South of Timber Yard Pt	monthly	1551391	5150721
SQ33593	Lake Ellesmere - Kaituna Lagoon	monthly	1572937	5150829
Surface water quality				
Site ID	Site name	Frequency	Easting	Northing
SQ34540	Waikewai Creek - Gullivers Rd	monthly	1548272	5144174
SQ30992	Harts Creek - Lower Lake Rd	monthly	1546793	5150435
SQ30916	Selwyn River - Coes Ford	monthly	1552688	5161709
SQ30878	L 2 River - Pannetts Rd	monthly	1555716	5161859
SQ32872	Halswell River - McCartneys Bridge	monthly	1561843	5163081
SQ30782	Kaituna River - Level Recorder	monthly	1574438	5155128
SQ30976	Boggy Creek - Lake Rd	quarterly	1548313	5153967
SQ30977	Doyleston Drain - Lake Rd	quarterly	1547960	5153366
Surface water: ecology				
Site ID	Site name	Frequency	Easting	Northing
SQ30976	Boggy Creek	annually	1548314	5153967
SQ30975	Hanmer Road Drain	annually	1549424	5155503
SQ00366	Harts Creek	annually	1543512	5149997
SQ00102	Kaituna Stream-upper	annually	1576563	5158515
SQ30782	Kaituna Stream-lower	annually	1574438	5155129
SQ00140	Prices Stream-lower	annually	1576357	5153325
SQ00139	Prices Stream-upper	annually	1576357	5153325
SQ30916	Selwyn River - Coes Ford	annually	1552689	5161710
SQ00034	Silverstream	annually	1550802	5163943
SQ00336	Jollies Brook (South Branch)	annually	1540014	5143299

3.2 CCC and SDC monitoring

The Te Waihora catchment area encompasses parts of both Christchurch City Council (CCC) and Selwyn District Council (SDC) and these agencies are required to carry out monitoring for consenting or regulatory purposes (Figure 3-1). CCC carry out regular monthly surface water monitoring in accordance with the requirements of the Interim Global Stormwater Consent (IGSC) consent number CRC090292. An annual report is published by CCC showing state, trends and comparisons with guideline levels, as well as commentary on areas of concern or interest. Table 3-2 shows surface water monitoring sites in the Te Waihora catchment, for this consent.

The parameters routinely tested include *E. coli*, *enterococci*, pH, electrical conductivity, DO (mg/L and % saturation), temperature, turbidity, TSS, NO_3-N, NO_2-N, NH_4-N, TN, DRP, TP; biochemical oxygen demand (BOD5); total and dissolved copper; total and dissolved lead, total and dissolved zinc, total hardness.

Table 3-2: CCC surface water monitoring sites (adapted from Table 1, Margetts & Marshall, 2015).

Halswell Catchment					
Site ID	Site name	Frequency	Easting	Northing	Classification
HALS01	Halswell retention basin inlet	monthly	2471698	5738633	not relevant
HALS02	Halswell retention basin outlet	monthly	2471793	5738525	not relevant
HALS03	Nottingham Stream at Candys Rd	monthly	2474530	5734689	spring-fed plains (pLWRP)
HALS04	Halswell River at Akaroa highway	monthly	2474444	5733330	spring-fed plains (pLWRP)
HALS05	Knights Stream at Sabys Road	monthly	2473720	5734461	spring-fed plains (pLWRP)

SDC does not carry out regular monitoring, but carried out monitoring in 2011 and 2014 related to Lincoln Stormwater Monitoring Programme (LSMP) consent CRC111663.1 with specific reference to Condition 15 (Table 3-3). The parameters tested include pH, electrical conductivity, DO (mg/L and % saturation), temperature, TSS, NH_4-N, TN, TP, dissolved copper, dissolved lead and dissolved zinc. Also rainfall at time of sampling. This was a one-off study only.

Table 3-3: Lincoln Storm water: surface water monitoring, 2013 (compiled from SDC data, 2014).

Lincoln Monitoring Programme				
Site ID	Site name	Frequency	ECan consent	Classification
1	Wetland	May, Sept	ISMP	
2	L II River	May, Sept	ISMP	
3	Moirs Lane	May, Sept	ISMP	
4	Southfield Drive	May, Sept	ISMP	
5	Greenslade Farm	May, Sept	ISMP	
6	L II Greenslade farm	May, Sept	ISMP	trigger site

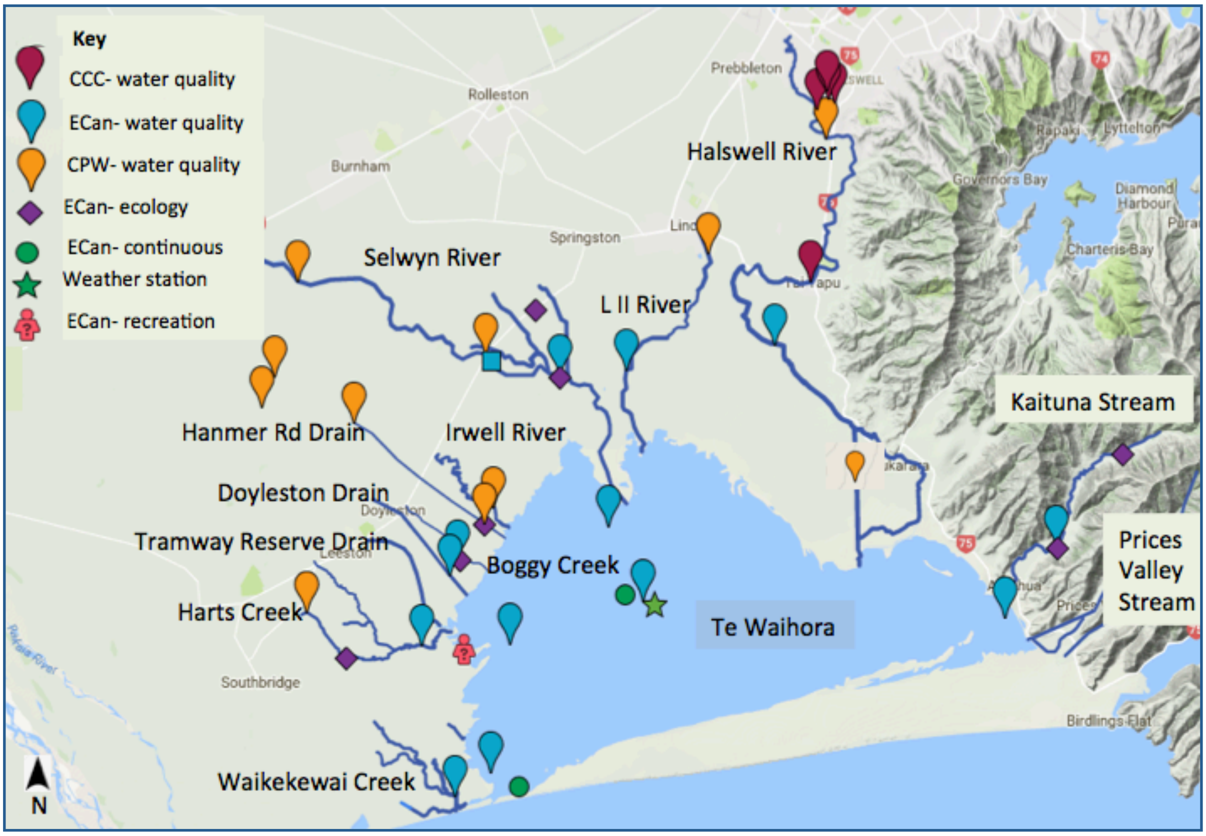


Figure 3-1: Water quality and ecology routine monitoring sites within the lower catchment of Te Waihora, 2015 (compiled from ECan and CPW data, 2016).

3.3 CPWL monitoring

Most ECan consent holders are individuals, companies, or trusts. The most significant industry stakeholder in the Te Waihora catchment is Central Plains Water Trust and the operating company, Central Plains Water Ltd (CPWL). As previously noted (section 1.6.4), this is an irrigation scheme company, which plays a large role in current and future water use and management in this area. Current surface water monitoring relevant to the lower lake catchment is shown in Table 3-4. Surface water monitoring sites are shown in Figure 3-2. Condition 28 of the CPWL resource consent requires CPWL to prepare an annual report describing monitoring results, and an interpretation of background conditions.

The parameters routinely tested include flow (gauged), *E. coli*, pH, electrical conductivity, DO (mg/L and % saturation), temperature, turbidity, NO_3-N, NO_2-N, NH_4-N, TN, DRP, TP.

Table 3-4: CPWL Lower catchment surface water quality monitoring programme (compiled from CPWL data, 2015).

Site ID	Site Name	Easting	Northing	Monitoring Type	Data Collection
SF1	Halswell Upstream Source LUS	1564401	5171690	Lowland (source)	CPWL
SF2	LII River Source LUS	1559333	5167164	Lowland (source)	CPWL
SF3	Selwyn River/Waikirikiri Source LUS	1549086	5162685	Lowland (source)	CPWL
SF4	Irwell River Source	1531019	5169145	Lowland (source)	CPWL
SF5	Hanmer Road Drain Source	1543810	5159693	Lowland (source)	CPWL
SF6	Boggy Creek Source LUS	1540709	5160655	Lowland (source)	CPWL
SF7	Doyleston Drain Source	1539745	5160180	Lowland (source)	CPWL
SF8	Harts Creek Source LUS	1542374	5151243	Lowland (source)	CPWL
T1	Halswell River (Duckpond Rd Bridge)	1565402	5157696	Lowland	CPWL
T2	LII River Downstream (Pannetts Road Bridge)	1555705	5161793	Lowland	ECan
T3	Selwyn River (Coes Ford)	1552643	5161694	Lowland	ECan
T4	Irwell River Downstream	1549788	5156245	Lowland	CPWL
T5	Hanmer Road Drain Downstream	1549408	5155495	Lowland	CPWL
T6	Boggy Creek Downstream (Lake Road)	1548309	5153895	Lowland	ECan
T7	Doyleston Drain Downstream (Lake Road)	1547957	5153373	Lowland	ECan
T8	Harts Creek Downstream (Lower Lake Road)	1546790	5150426	Lowland	ECan

3.4 Other stakeholder monitoring

Lincoln University

A compilation of LU water quality monitoring data for the Te Waihora catchment is available (WCFM Report 2012-001). This report is a database of the water quality carried out by LU from 1993 to 2011, within the lower catchment (Ruske, 2013). Current monitoring carried out by students (WATR402) and others include sites at Coes Ford, Powells Drain, L I (Lincoln), and Te Waihora at the Lower Selwyn Huts. Figure 3-2 shows surface water quality monitoring sites. Frequency is once per year for some sites but variable for others. The parameters tested at various sites and times include flow, *E. coli*, *Salmonella*, pH, electrical conductivity, DO (mg/L and saturation), dissolved carbon dioxide, temperature, turbidity, TSS, NO_3-N, NH_4-N, TN, DRP, TP, biochemical oxygen demand (BOD5), total hardness. Not all parameters were tested at all sites.

Table 3-5: Stakeholder surveys in the Te Waihora catchment.

Living Water-Ararira/L II			
Site name	Frequency	Classification	Type
L I	April, July	spring-fed plains	tributary
Liffey	April, July	spring-fed plains	tributary
LMD	April, July	spring-fed plains	tributary
Springs	April, July	spring-fed plains	tributary
Goodericks	April, July	spring-fed plains	tributary
Ellesmere	April, July	spring-fed plains	tributary
Powells	April, July	spring-fed plains	tributary
Englishs	April, July	spring-fed plains	mainstream
Pannetts	April, July	spring-fed plains	mainstream
Wolfes	April, July	spring-fed plains	mainstream
Kaituna Community			
Site name	Frequency	Classification	Type
SH75	Oct to Aug monthly	Banks Penin stream	stream
Recorder	Oct to Aug monthly	Banks Penin stream	stream
Okana Stream	Oct to Aug monthly	Banks Penin stream	stream
Middle Reserve	Oct to Aug monthly	Banks Penin stream	stream
Parkinsons Rd	Oct to Aug monthly	Banks Penin stream	stream
Kowhai Hills	Oct to Aug monthly	Banks Penin stream	stream
Parrs	Oct to Aug monthly	Banks Penin stream	Stream
CAREX			
Site name	Frequency	Classification	Type
Selwyn tributary-Silverstream	Monthly	Spring-fed plains	tributary

Figure 3-2: Lincoln University surface water quality monitoring sites (CPWL, 2015).

The currently monitored parameters as well as Kaituna Valley and the L II River surveys are shown in Table 3-6 below.

Table 3-6: Compiled data showing parameters monitored monthly by ECan, CPWL and CCC, as well as two recent surveys by Kaituna Valley Stream and L II River stakeholders (2016).

	Tributaries					Lake
Parameters	**ECan monthly**	**CPWL monthly**	**CCC monthly**	**Kaituna**	**L II**	**ECan monthly**
water discharge/ level	x	x				x
temperature	x	x	x		x	x
pH	x	x	x			x
electrical conductivity	x	x	x			x
dissolved oxygen	x	x	x		x	x
clarity/secchi disc	x	x	x			x
turbidity	x	x			x	x
total suspended solids	x		x	x	x	x
calcium			x			
magnesium			x			
sodium						
potassium						
chloride						
fluoride						
sulfate						
alkalinity						
nitrate plus nitrite	x	x	x	x	x	x
ammoniacal nitrogen	x	x	x	x	x	x
total nitrogen	x	x	x	x		x
dissolved reactive phosphorus	x	x	x	x	x	x
total phosphorus	x	x	x	x		x
silica, reactive						
Chorophyll a						x
E Coli	x	x	x	x	x	x
Enterococci			x			
BOD5			x			
copper			x		x	
lead			x		x	
zinc			x		x	

3.5 Catchment improvement initiative monitoring

Within the Selwyn–Waihora catchment area, many actions (both voluntary and through legislative change) are being taken by many stakeholders to improve and enhance the surface water quality. The Freshwater Improvement Fund has committed one hundred million dollars over ten years to improvement initiatives throughout New Zealand (MfE, 2017a).

Other funded interventions relating to water quality (funded by MfE and others) include:

- restoration and enhancement of specific cultural sites and mahinga kai
- activities to protect and restore the lake margin wetland habitats and existing indigenous vegetation and wildlife
- restoration of specific lowland tributary streams and riparian habitats
- activities to improve the lake and catchment management practices by focusing on sustainable land use and drainage practices
- development of a robust monitoring and investigations programme as part of WTW

Within Canterbury, riparian planting on tributaries has been undertaken for more than thirty years (Quinn & Williamson, 1993). Little monitoring or evaluation of its effect on water quality have been done (Collins, 2011) and those that have been, compared restored areas with non-planted areas at the same time (Parkyn et al., 2003) or the same area before planting and ten years later (Jowett et al., 2009). Collins (2011) instead, compared water quality upstream of plantings and downstream of plantings at the same times using a combination of water quality parameters and invertebrate community assessment (stream health) for assessing the water quality. The effectiveness depended upon buffer width, buffer continuity, fencing timescales and shading. The three parameters Collins found to be most affected by riparian planting were conductivity (increase), turbidity (decrease) and dissolved oxygen (increase). Flood flows were not included in the results (Collins, 2011).

Recent initiatives such as WTW and Living Water (section 1.5.3) have specific riparian planting projects (these are included in Figure 3-3) and several monitoring surveys have been undertaken, but obvious results attributable to specific actions have so far been difficult to show (Collins, 2011).

This overarching integrative water quality monitoring programme specific to Te Waihora is not be able show these small-scale changes, but data could be used as a foundation on which to base testing parameters and sites for future monitoring to detect specific small-scale effects. Monitoring is carried out as close as possible to the discharge points of the surface water and will show cumulative changes only, reflecting the whole catchment; the reasons for the change may not be accurately identified.

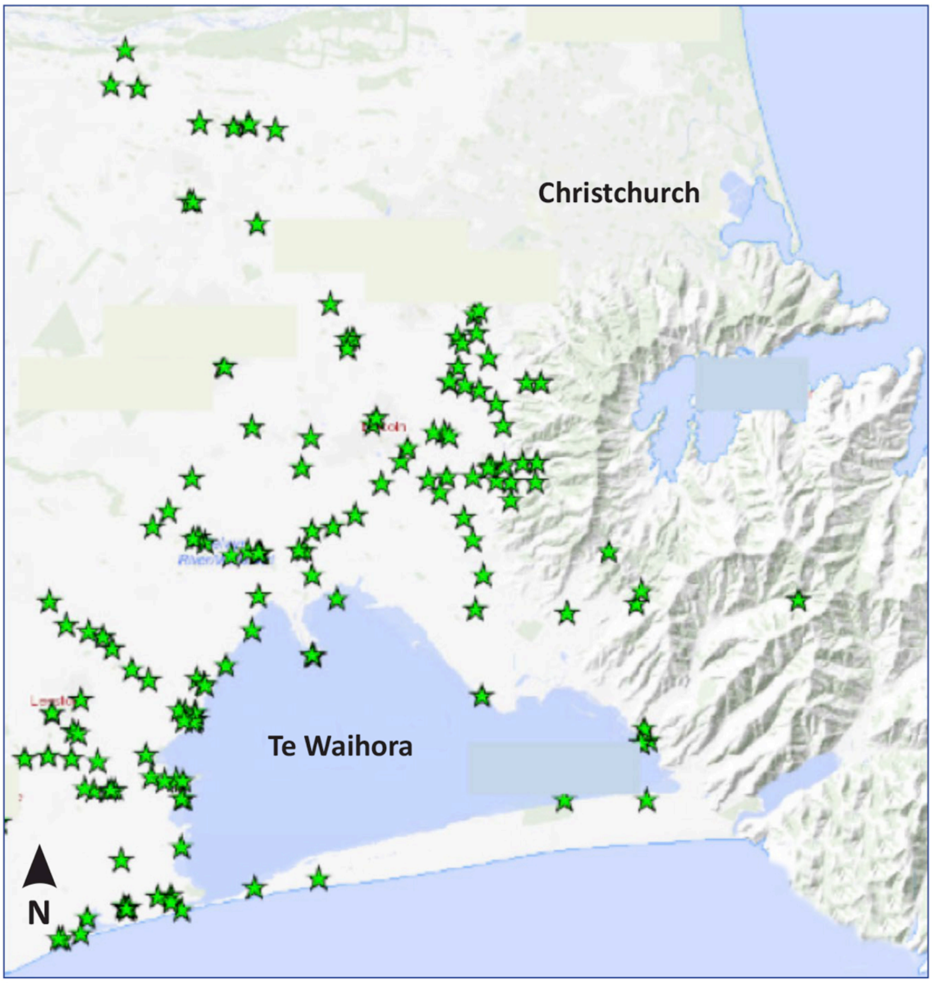


Figure 3-3: Some of the restoration planting within the lower catchment (ECan, Canterbury Maps, 2013).

Chapter Four – Results

Water quality monitoring programme design

4.1 Programme objective

In New Zealand, water quality monitoring is a part of the Environmental Reporting Regulations (ERR) 2016 (MfE, 2016e), wherein the state of the water quality, the resulting pressures and the impact these have within the framework of the four well-beings of the RMA, must be captured and documented according to the National Objectives Framework (NOF) for ecosystem and human health for recreation (MfE, 2016b). A monitoring programme must document the *state* of a specific freshwater body at the chosen place at the chosen time, take into account the *pressures* placed upon it (e.g., land use, point-source and diffuse-source pollution) and capture the *impact* of this water quality on the four well-beings (environmental, economic, social and cultural). Strobl and Robillard (2007) state that many monitoring programmes are without a logical and consistent design strategy, while Chapman (1996) confirms that clear objectives are fundamental to logical, consistent design. The Water Framework Directive (WFD) of the European Community has published new guidelines, which set out similar requirements (to New Zealand) and confirm that the design of monitoring programmes has to be specific to a local area but consistent with national guidelines.

The first step in the design of a monitoring programme for Te Waihora water quality, is to determine its main objective, one that is consistent with plans outlined in the ZIP Addendum (ECan, 2013), and takes account of traditional principles, current legislation (NPS-FM (2014) amended 2017 and the CLWRP) and incorporates the relevant local aspects.

The overarching objective is therefore:

to assess the state and trends of water quality in Te Waihora and its immediate catchment with secondary objectives:

to identify sub-catchments impacting on lake water quality and to detect long-term response to change (e.g., in land use, catchment restoration and climate change)

The key components of a robust water quality monitoring programme are the selection of monitoring sites, water quality parameters and the frequency of monitoring, allowing for current and possible future requirements of the environment. To determine change, long-term data with standardised and stable protocols (quality control in all aspects) are necessary (Davies-Colley et al., 2012).

Measuring the input load of sediment and nutrients is required for lake water quality management to identify sources, particularly for Te Waihora, as sediment suspension and re-suspension are a major concern. High nutrient levels can potentially cause an algal bloom but research has shown that the level of turbidity within the lake affects the degree of algal bloom in Te Waihora (Gerbeaux and Ward, 1991). Cost-effectiveness is always a consideration and one that affects all three components. This requires the weighting of sites (considering whether one is more representative than the other), the use of indicator parameters (e.g., *E. coli*) to give a more cost-effective option and optimising the frequency of sampling to reduce cost while still achieving detectable and reliable trend analysis.

4.2 Tributary and site selection—application of criteria

The primary selection of sites for this monitoring programme focused on the spatial variability in water quality (requiring many sites), as well as detecting both diffuse and point-source pollution. In its design principles, the National Environmental Monitoring and Reporting project (NEMaR) recommends that water quality and ecology monitoring sites be integrated when considering site selection (MfE, 2014). There is however, some debate around how practical this is, particularly at non-wadeable sites, such as the L II River. Therefore, this has not been considered a criterion in this design but is considered in the site choice where practicable.

The NPS-FM (2014) requires a water quality sampling site to be representative of the “freshwater management unit”, but site selection is inherently difficult in lowland, spring-fed catchments due to the difficulty of selecting a site that is representative of that subsurface and surface catchment (MfE, 2014). Criteria 1 and 2 for site selection take this requirement into account by considering all spring-fed tributaries of the lake to be spring-fed except for Kaituna and Prices Valley, which are Banks Peninsula river types (ECan, 2011).

Careful consideration for the selection of tributaries is shown in Table 4-1a utilising the 'weighting' of attributes shown in Table 4-1c. The high rainfall peak flows of the eastern catchment are taken account of as part of the annual % inflow (Criterion 2), while the influence of the lower catchment drainage systems described in section 1.5.6 are taken account of as a part of Criteria 2, 3 and 4 for inflow, possible point-source and diffuse pollution.

Some criteria are pass/fail (criterion 5—RMA, criterion 8—fresh water/lake water interface, criterion 9—land ownership, criterion 10—safety). Criteria 3 and 4—pollution detection generally, must be weighed up alongside inflow and historical data unless an extremely significant pollutant has been detected previously. Identification of the pressures within each tributary catchment indicate possible pollutants and the most appropriate site for detection. These are considered in the surrounding land use, relationship to towns and consented areas for dairy effluent spreading (associated with many dairy farms) as pressures associated with each site/tributary choice. This procedure is confirmed by MfE, who recommend more attention is given to large streams and potential pollution areas (Elliott & Sorrell, 2002).

Routine revision and confirmation of site selection is an integral part of the operation of a monitoring programme, particularly if physical attributes change over time (e.g., inflows). Short surveys or surveillance studies may be necessary for clarification of a specific objective, and are considered for site selection, for example, when detecting, verifying and finding the source of pollutants, or establishing lake loads.

The Te Waihora water balance is approximately 65% surface water inflow, 30% rainfall and 5% from underground aquifers, as shown in Figure 1-10 (Clausen & Horrell, 2007).

Water quantity is an obvious essential attribute for site selection but the percentage inflow of each tributary appears to be variable (Table 2-5) possibly due to climate change, change in type and volume of irrigation in inland catchments, change in snow-fed rivers (the Selwyn River for example shown in Figure 4-1), rainfall and drought, cessation of water races, or other undocumented causes. Table 2-5 appears to show a decrease in the cumulative total median flow (from 10.29 to 7.7 m^3s^{-1}) and a change in the relative contribution of each tributary (data to mid 2017). Many of the smaller streams/drains have been dry in recent years (Kelly et al., 2014). This change in inflow ratios (resulting in a change in tributaries) may require further research.

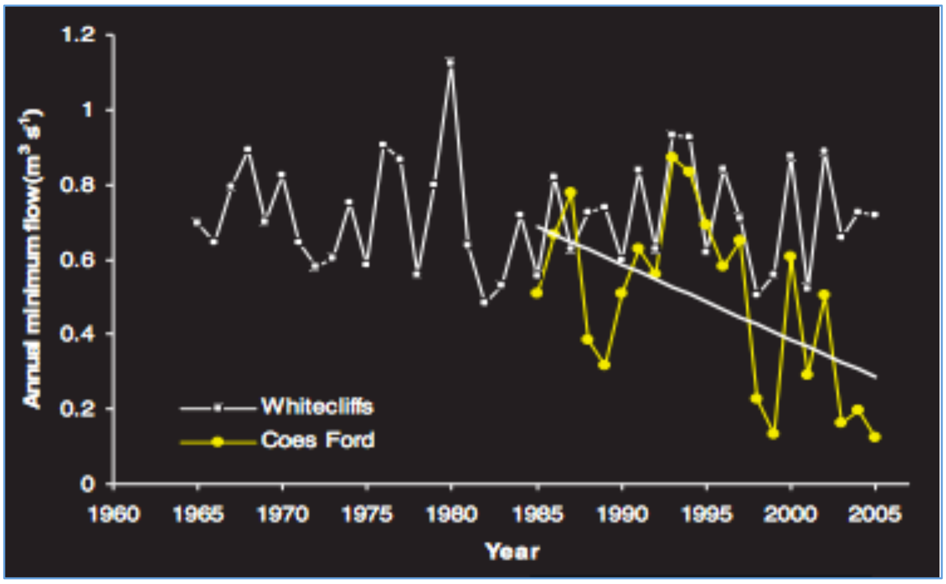


Figure: 4-1: Declining annual minimum flows in the Selwyn River (McKerchar and Schmidt, 2007).

The following section identifies primary sites for this monitoring programme, but additional sites could be triggered by set criteria if this was required in the future. For example, intermittently flowing drains/streams could be gauged and sampled for water quality when a connected stream/river reaches a specific flow threshold or for a flood event. This will aid in the detection and documentation of loads.

Please note that the order of the tributaries for this programme was to start at the southern area adjacent to where the lake is opened (Waikekewai Creek) and proceed in a clockwise direction to Kaituna, Prices Valley and Kaitorete Spit.

4.2.1 Tributary monitoring sites

Initially all waterways/tributaries shown in Table 2-5 were considered for possible sampling sites, then ephemeral drains were excluded (as many of the pre-set criteria are not met) resulting in the 'possible' tributaries shown in Table 4-1a. These tributaries were then assessed and ranked against the predetermined criteria (Table 4-1a and 4-1b) for tributary and site selection. The top 8 tributaries were selected. During the interface conductivity sampling survey, Doyleston Drain Road Drain had almost no flow for the majority of the testing, Hanmer Road Drain had very little flow, and the Irwell River was a series of puddles, so they were not included as monitoring sites despite their history of monitoring. Golder Associates (2012) note similar findings. This problem will require review in the future especially if the present climate patterns change.

Tables 4-1a and 4-1b show the assessments where a ✓ indicates the tributary meets the established criteria. Criteria 1, 2, 3, 6 and 7 have been weighted and ranked according to Table 4-1c. Criteria 4 and 5 apply to all sites. Criterion 8 is the criterion that requires further recommendations and testing. Criteria 9 and 10 are pass or fail, so do not require any weighting.

Selection of the site on a chosen tributary was to establish the most downstream site not affected by lake water, to include as many streams and drains (and their catchments) as possible, and then (if valid) the cost-effectiveness of using long-term historical data (from an already-monitored site) versus starting a new site. Significant surface water quality differences between a proposed site and a currently monitored site would need to be clearly documented.

The five tributaries (Tramway Reserve Road Drain, Doyleston Drain, Boggy Creek, Hanmer Road Drain and Irwell River) draining and discharging into the western side of Te Waihora were assessed as physically similar (although the Irwell River may be less modified for drainage) with similar land use in each catchment. However as noted, only two were flowing.

Table 4-1a: Criteria attributes for the selection of possible tributaries.

		Criteria				
		1	2	3	4	5
Tributary	catchment (ha)	spatial representativeness	max % inflow (a)	possible p/s pollution	diffuse pollution	regulatory compliance
Southern						
Waikekewai	1443	✓	2%		yes	✓
Western streams						
Harts Creek	1913	✓	18	yes	yes	✓
Tramway Reserve	933		2	yes	yes	✓
Doyleston Drain	785		3		yes	✓
Boggy Creek	1503		2.5		yes	✓
Hanmer Rd Drain	2242		1		yes	✓
Irwell River	1835		9		yes	✓
Major rivers						
Selwyn River	18,267	✓	30		yes	✓
L II	2900	✓	29	yes	yes	✓
Halswell	16,520	✓	11	yes	yes	✓
Banks Peninsula						
Kaituna	4197	✓	8		yes	✓
Prices Valley	1846		1		yes	✓

(a) max % according to Table 2-5

Table 4-1b: Criteria attributes for site selection on the chosen tributary.

		Criteria			
	6	8		9	10
Tributary	historical data	conductivity site	Distance (m) to lake	land ownership	access & safety
Waikekewai	some data	3	300	Ngāti Moki rūnanga	✓
Harts Creek	yes	5	1963	public	✓
Tramway Reserve	some data	2	500	DOC	✓
Boggy Creek	yes	2	500	DOC	✓
Selwyn River	no	7	6860	public	✓
L II	1984-2014	1	1570	public	✓
Halswell	yes	2	4000	public	care
Kaituna	yes	2	10,297	public	off bridge
Prices Valley	no	2	2,380	public	✓

Table 4-1c: Weighting of attributes for tributary selection and weighting key.

	Criteria number					
	1	2	2	3	6	7
	representative of category	flow permanance	% inflow	possible p/s pollution	historic data	Total 'weight': top 8 chosen
Waikewai	5	5	1		4	15
Harts Creek	5	5	4	5	5	24
Tramway Rd Drain	4	5	1	5	3	18
Doyleston Dr Rd Drain	3	1	1		5	10
Boggy Creek	4	2	1		5	12
Hanmer Rd Drain	4	1	1		3	9
Irwell River	3	1	2		5	11
Selwyn River	5	5	5		4	19
L II	5	5	5	5	5	25
Halswell	5	5	3	5	5	23
Kaituna River	5	5	2		5	17
Prices Stream	3	5	1		3	12

Weighting Key:	1	2	2	3	6
weight #	spatial representativeness	% flow permenence	% inflow	possible point source pollution	historic data
5	best	>91	>25	yes	yes
4	possible	91 to 99	15 to25		trib not site
3	short flowing reach	85 to 90	10 to 14		some
2		71 to 84	5 to 9		
1		dry 2016	<5		no data

The programme tributary choice is due to the flow (or no-flow) in the Irwell River, Doyleston Drain and Hanmer Road Drain, as well as a better spatial spread of the monitored tributary catchments across the western lake area. Possible point-source contamination downstream of Leeston Sewerage Scheme has also been identified as a possible contaminant. Doyleston Drain has a water level recorder and was considered instead of Boggy Creek, but rejected due to its low water flow.

Monitoring Site 1 (MS1): Waikekewai Creek

The Waikekewai Creek is a small spring-fed stream with four main tributaries in the southernmost area of Te Waihora. The Waikekewai Creek would once have drained the area of Southbridge, but is currently a spring-fed stream rising east of the Leeston-Taumutu Road and flowing east, discharging into Te Waihora through a long inlet close to where Te Waihora is opened to the sea (Figure 4-2). The Parkin Drain (the eastern tributary) is usually a flowing reach, becoming Sedgemere Creek, as well as ephemeral drains and water races. The Taumutu Stream branch (part of the Taumutu drainage system) rises from a large spring 1 km inland of the Pacific Ocean and meanders just inland of the beach until it joins the Waikekewai Creek downstream of the Ngāti Moki Marae and 350 m before the discharge point. The catchment as outlined by ECan is 1443 ha, but the flowing reach begins approximately 5 km from the discharge point. The Taumutu Creek branch of the tributary may capture changes in water quantity associated with the diverse water recharge in the Little Rakaia area close to the Rakaia River. It provides up to 2% of the inflow to Te Waihora (Table 2-5) but continued flowing during the 2016–17 drought. The flow at that time appeared to be greater than 50% from Taumutu Stream.

Land use in the wider catchment (Figure 4-3), is primarily arable, but with dairying forming a significant percentage of the heavier soils of the lower catchment area. These areas are adjacent to the main Waikekewai branch and upstream of the Ngāti Moki marae. Pressures on this tributary are primarily from diffuse pollution and sediment due to rainfall run-off.

Initial conductivity measurements (in March 2016) to establish the fresh water/lake water interface are shown in Figure 4-2 and the associated Table 4-2. One conductivity reading at conductivity site 3 (along the Church Road) in May 2016 was higher than expected, but the reason could not be established and was possibly due to activity upstream at that time. It did not appear to relate to the lake level. The following reading (at that site) with a higher lake level was similar to previous readings. The opening/closing of the lake, wind and stream flow do not appear to have any major effect on this waterway (Table 4-2), possibly due to its discharge into a small inlet/lagoon.

Site 6, beside the marae (900 m from lake, ECan- SQ34540), is the site monitored by ECan, but it is upstream of the confluence with Taumutu Stream (Figure 4-2). The Taumutu Stream branch contributed more than 50% of the water entering the lower reach (at the time of survey), before discharging into the lake. This branch is clean and clear and documented by ECan as a reference site. Site 6 (upstream) and Site 3 (downstream) are located above and below a new riparian planting area. Sediment is a major factor for Te Waihora, giving accurate load data a high priority. Site 3 (300 m from the discharge into the lake), has been chosen as MS1 (Figures 4-2 and 4-4) to give more accurate data, but with the suggestion that a significant duplicate survey/surveillance is carried out over 12 to 24 months, to validate this site. The objective of this monitoring programme is to monitor the water quality in the tributary as close as possible to its discharge into the lake, to attain accurate load data.

The survey Site 4 is an ECan reference point. Reference points are streams with minimal disturbance from anthropogenic use and are considered important in the design of a water quality monitoring programme as they represent a best-state baseline for comparisons (Kelly et al., 2014).

The Waikekewai Creek has been included in the Te Waihora monitoring programme for several reasons. It falls in the top eight weighted tributaries, it is culturally and environmentally of high importance, it is included in the *State of the Lake* reported sites and the Taumutu Stream branch is an ECan reference point. Waikekewai Creek has considerable riparian improvements and is an area targeted by WTW. Golder & Associates (2011) state that this tributary has low to moderate ecological values. *State of the Lake* (Lomax et al., 2015) water quality grade is fair (Site 6 beside marae, ECan SQ34540). The ZIP Addendum outlines the Sustainable Drainage Management Package, which includes the Waikekewai drainage network. Drain maintenance may cause brief increases in sediment as seen at Site 9 September 2016. The site has very easy access, is safe for sampling and is suitable for cultural assessment.

The effect of changes in farming systems (where farm environment plans and best management practices for all farming activities are implemented and audited) on water quality would be reflected at both sites, additionally, any change in water quantity will also be recorded. The effect of CPWL may be seen in postulated increases in groundwater level, or conversely in a reduction in groundwater levels due to a change in the flow patterns of the braided Rakaia River. Several of the lake’s commercial fishermen have their base at the mouth of the discharge inlet.

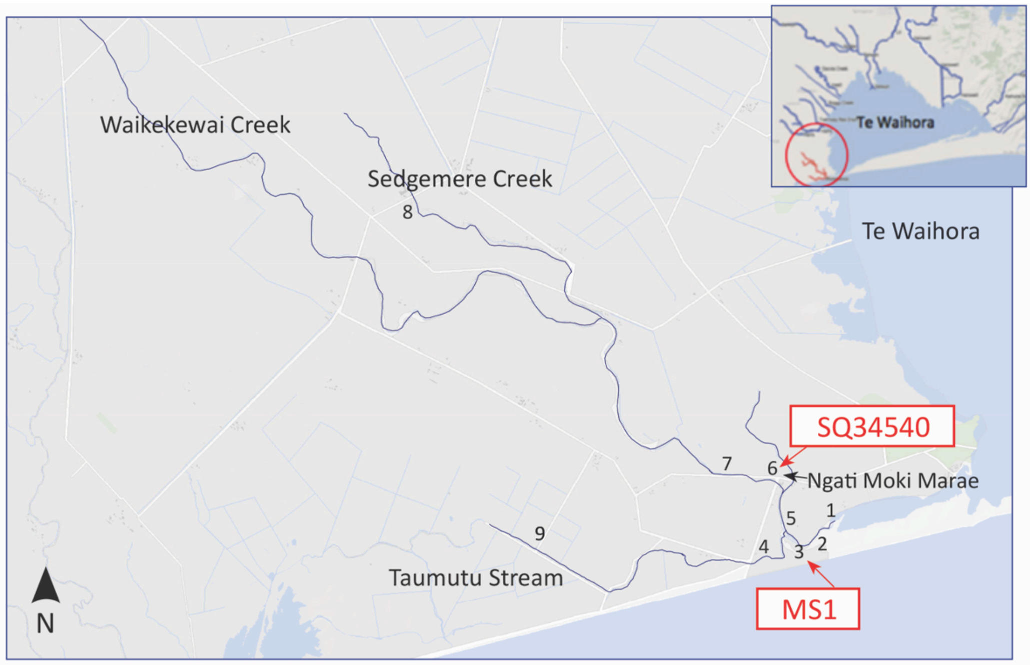
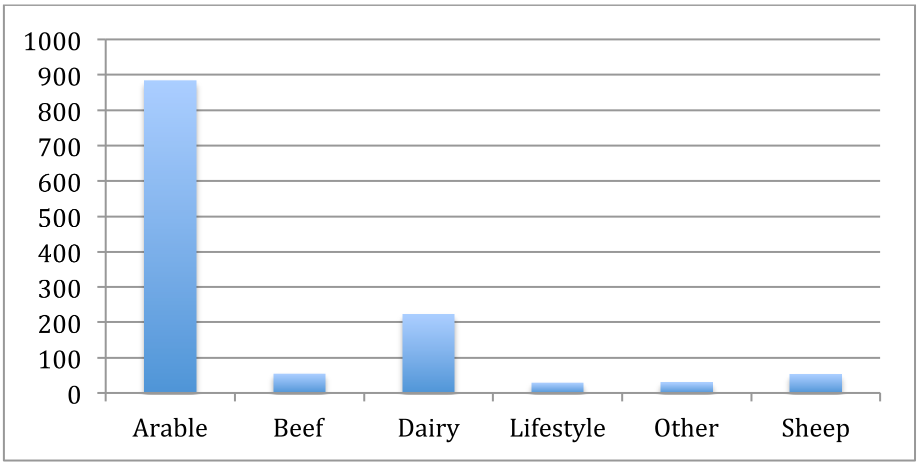


Figure 4-2: Waikekewai Creek showing location, conductivity sites 1 to 9 (as per Table 4-2), programme monitoring site (MS1) and ECan monitoring site (SQ34540) (compiled from Canterbury Maps, 2016). Map scale approximately 1 cm to 500m.



Figures 4-3: Land use areas (ha) in the Waikekewai catchment (1443 ha). (Compiled from Agribase data, 2015).

Table 4-2: Waikekewai Creek conductivity (µS/cm) survey showing temporal and spatial readings (2016).

		March	May	May	June	July	August	Sept	Oct
Lake level (masl)		0.70	0.77	0.88	1.10	0.76	0.80	0.96	0.64
Lake open/closed		closed	closed	closed	closed	open	closed	closed	open
Wind(km/hr)		NNE-20	NW-strong	SSW-22	no wind				SW-24
Flow at site 6 (marae)(m3/s)		0.020	0.010	0.010	0.087	0.035	0.035	0.056	0.033
Sites	m from lake								
0	*0*	18,280							
1	*30*	328							
2	*120*	253							
3	*300*	250	239	305	246	251	248	248	242
4	*370*	233			250			254	
5	*740*	256							
6	*900*	248			269		273	275	257
7	*1200*	278							
8	*5500*						290		
9	*3100*						236	720- earth works	

Figure 4-4: Waikekewai Creek at MS1 (2016).

Monitoring Site 2 (MS2): Harts Creek

Harts Creek is a lowland spring-fed creek rising 2.6 km southwest of Leeston. It has two main tributaries, Harts Creek and Birdlings Brook, and is one of the larger tributaries to Te Waihora (12%–20% of the inflow) as shown in Figure 4-5. The catchment area is 1912 ha.

The level of the lake has a significant effect on Harts Creek (Table 4-3). A sediment plume (Figure 4-8) was clearly visible moving up the creek as the lake level rose. This plume had no further influence after approximately 400 m. Conductivity did not change significantly from Site 3 (400 m from discharge) to Site 5 (approximately 2000 m from the discharge point) where the stream flows within well-defined banks with no further tributaries joining.

Birdlings Brook (Figure 4-5) is a tributary of Harts Creek, and is downstream of the southern area of Leeston (population 1500 in 2016) where drainage of the Leeston Creek area has historically been a problem after heavy rain events. Land use is mainly beef, sheep, arable and dairy (Figure 4-6), with dairy farming on the heavy soils nearer to the lake.

Harts Creek has a water level recorder at Site 5 (ECan monitoring site SQ30992). An active and well-respected stream-care group has carried out riparian restoration for many of the lower reaches since the 1990s. This area is regarded highly for its environmental attributes and has moderate to high ecological values (Golder Associates, 2012). The *State of the Lake* (Lomax et al., 2015) water quality grade is poor (at Lower Lake Road SQ30992), despite the mature riparian planting along many of the stream banks. This is due mainly to high N levels.

Harts Creek has been chosen as a monitoring stream in accordance with established criteria and Site 5 (MS2) at Harts Road chosen as the monitoring site. The monitoring site on the stream could have been selected at any practical point upstream of the 400 m point, but the weighting of historical data, the proximity of the recorder, as well as ease and timing of sampling, showed Site 5 to be the best option. A good relationship for flow has already been established at this site. Routine monitoring at this site will capture anticipated environmental improvements, effects of CPWL, or any possible future pollution. This site is accessible from the public road with safe vehicle parking, access and sampling aspects. It is suitable for cultural assessment.

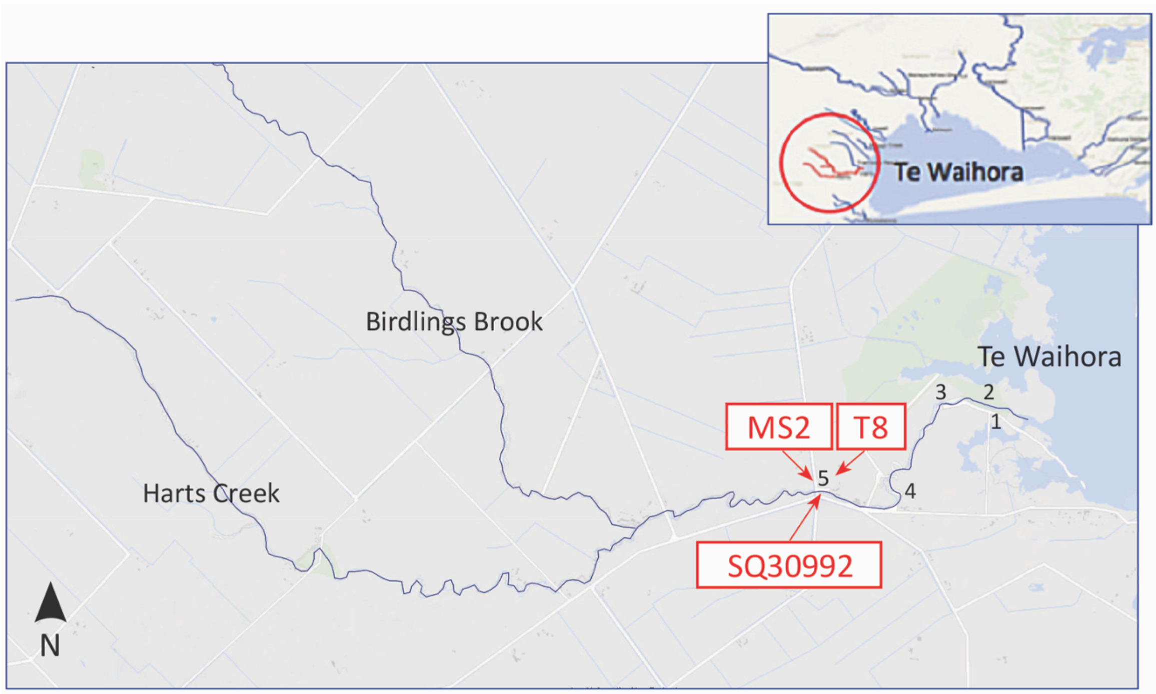
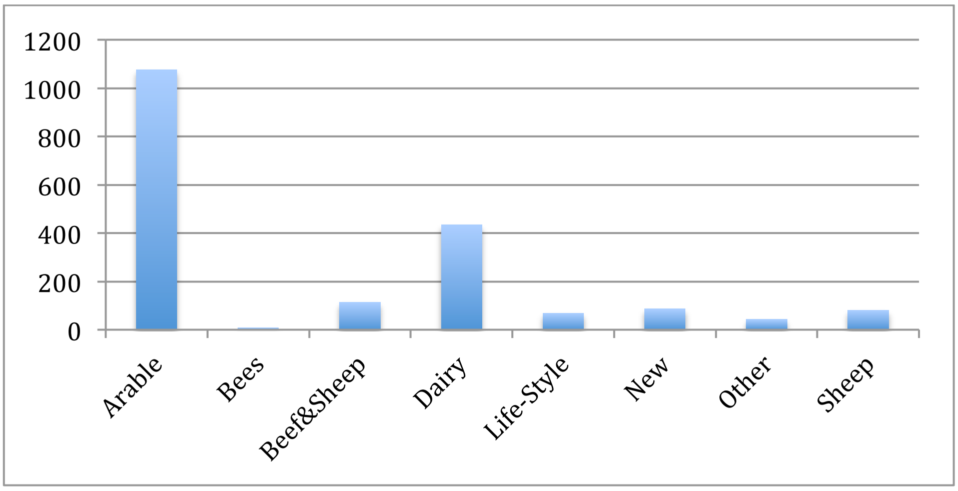


Figure 4-5: Harts Creek showing location, conductivity sites 1 to 5 (as per Table 4-3), programme monitoring site (MS2), ECan (SQ30992) and CPWL (T8) monitoring sites (compiled from Canterbury Maps 2016). Map scale approximately 1 cm to 400m.

Table 4-3: Harts Creek conductivity (µS/cm) survey showing temporal & spatial readings (2016).

		March	June	July
Lake level		0.70	1.10	0.76
Lake open/closed		closed	closed	open
Wind		NNE-20	no wind	
Flow(m^3/s) at Site 5		0.62	0.83	0.90
Sites	m from lake			
0	*0*			
1	*150*	304		
2	*215*	232	315	248
3	*400*	210	242	246
4	*1280*	208	243	248
5	*1963*	211	241	244



Figures 4-6: Land use areas (ha) in the Harts Creek catchment (1912 ha). (Compiled from Agribase data, 2015).

Figure 4-7: Harts Creek at MS2 (2017).

Figure 4-8: Lake plume moving upstream in Harts Creek, Site 2 (June 2016).

Monitoring Site 3 (MS3): Tramway Reserve Road Drain

Tramway Reserve Road Drain is situated close to, and southeast of, the village of Leeston (Figure 4-9). It is a part of the original Leeston Creek waterway system and has been altered to drain this area. It includes the northern aspect of the recently completed Leeston Drainage System and is directly downstream of the Ellesmere sewerage effluent spreading scheme (Figure 4-9). Tramway Reserve Drain contributes up to 2% of the inflow to Te Waihora (Table 2-5). The catchment area is 464 ha.

The Tramway Reserve Trust established in 2002, has carried out significant areas of (now mature) riparian planting (as seen in Figure 4-11) along Tramway Reserve Drain. The Tramway Reserve Drain catchment is also a priority area for riparian planting, as per WET (Rennie, 2012). The pressures on this tributary are future anthropogenic pollution if the Ellesmere Sewerage Scheme has an overload problem, catchment land use and climate change.

The conductivity survey (Figure 4-9 and Table 4-4) showed significantly higher conductivity readings at Site 3 (900 m from the lake), than at Site 2 (500 m from the lake). This is due to a spring flowing into the wetland area slightly northwest of Site 2 and joins Tramway Reserve Drain near this site. Site 2 (Figure 4-9) at the DOC gates has easy access and is in a convenient location to other routine monitoring sites (with easy access from The Lake Road), but the addition of a site without historical data requires a significant survey to establish the cost-effectiveness of this in relation to the data gathered for management purposes. As previously noted, the positive (increase in robustness and longevity due to the drought conditions in 2015 – 2017) and negative (loss of valuable historical data) aspects of a change in site will require careful consideration and research to validate. This site is suitable for cultural assessment.

Additionally, although Tramway Reserve Drain is not currently monitored, due to its position relative to population and the Ellesmere Sewerage Scheme, the changes in other Te Waihora tributary flows (Doyleston Drain and Boggy Creek have traditionally been monitored quarterly by ECan but both are currently less reliable) and as representative of a consistently flowing waterway, this tributary is included in the monitoring programme as representative of the western boundary streams/drains. The adjacent land use is similar to the surrounding catchments, which include a significant area of intensive pastoral farming (Figure 4-10). It is noted that although it is not a large percentage of Te Waihora's total input, during the recent drought (2016–17), this waterway continued to flow. There are some historical data available for a site at Lake Road (SQ35155, 2007), upstream of the chosen site. An associated ECan water quality site (SQ34662) is directly downstream of the sewerage discharge area but 4 km upstream of Site 2. It is monitored biennially.

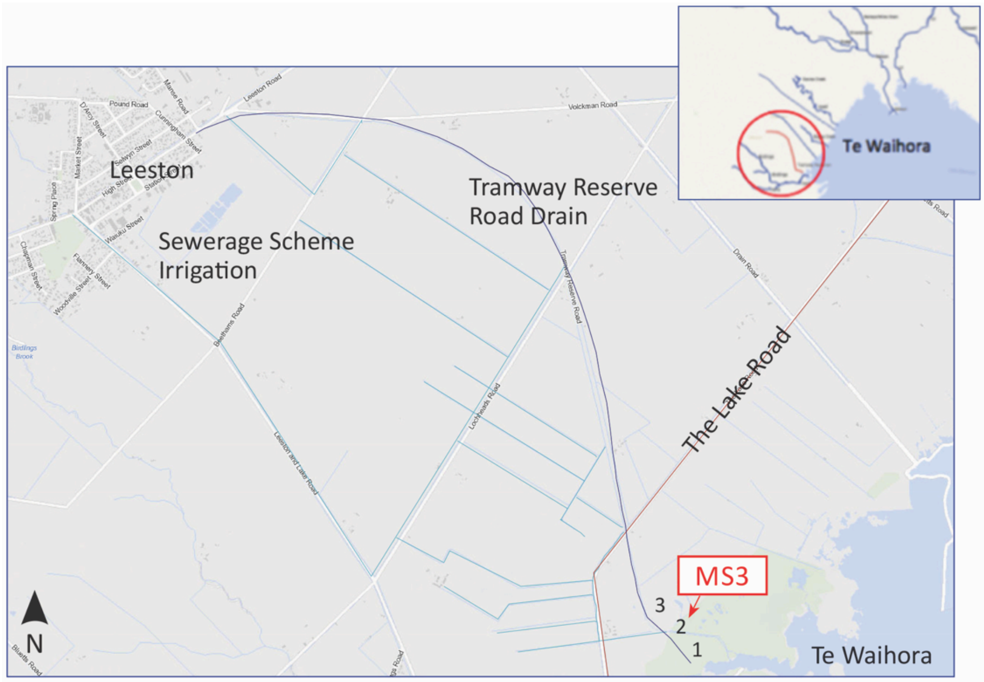
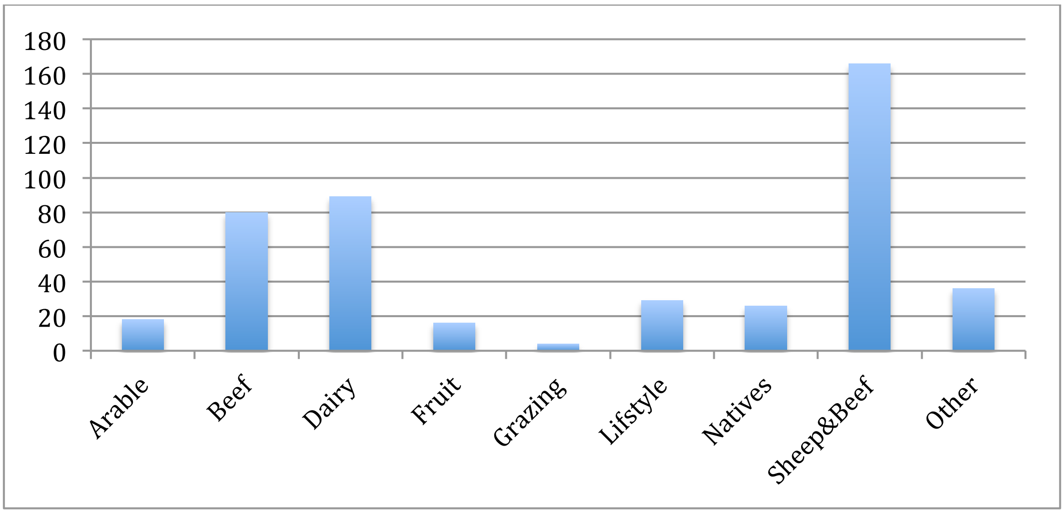


Figure 4-9: Tramway Reserve Road Drain showing location, associated drains (light blue), conductivity sites 1 to 3 (as per Table 4-4) and programme monitoring site (MS3) (compiled from Canterbury Maps 2016). Map scale approximately 1 cm to 500m.

Table 4-4: Tramway Reserve Drain conductivity (µS/cm) survey showing temporal and spatial readings (2016).

		March	June	Sept	Oct
Lake level		0.70	1.10	0.96	0.64
Lake open/closed		closed	Closed	closed	open
Wind		NNE-20	no wind		SW-24
Sites	m from lake				
1	*350*	244	290		
2	*500*		287		
3	*900*			353	350



Figures 4-10: Land use areas (ha) in Tramway Reserve Road Drain catchment (464ha). (Compiled from Agribase data, 2015).

Figure 4-11: Tramway Reserve Road Drain at MS3 (2016).

Monitoring Site 4 (MS4): Boggy Creek

Boggy Creek originally rose from what is known as the Killinchy Swamp. Many drains now join the creek as it winds southeast towards Te Waihora. It is a spring-fed lowland stream and is a part of the Leeston Lowland Central Plains Drainage Scheme administered by SDC. Boggy Creek contributes up to 2.5% of the inflow to Te Waihora (Table 2-5). It has a catchment area of 1503 ha and land use is largely dairying (Figure 4-13).

This waterway is representative of the south-easterly flowing streams/drains in this area. Boggy Creek has had regular gaugings at the Lower Lake Road site (ECan site SQ30976) since the 1970s. It is weighted in the top eight tributaries. It has high public interest with several improvement initiatives carried out over many years by environmentally progressive farmers adjacent to this stream. Living Streams have a restoration project between Rushbrooks Road and Volckman Road. The upper reaches of Boggy Creek are historically ephemeral. An augmentation trial was carried out in the Boggy in 2015.

The conductivity survey (Figure 4-12 and Table 4-5) showed that the lake water affected the stream for a relatively short distance. The conductivity from 200 m from the discharge point (Site 2) was found to be lower than the conductivity at The Lake Road site (Site 4). This is possibly due to increased inflow from Collets Road Drain and/or further springs flowing into the stream. The flow increases significantly downstream of Collets Road Drain confluence. The fresh water/lake water interface is downstream of Site 2 and, again, the debate is around the change in conductivity from the dilution effects of incoming drains/tributaries and their effect on load discharged into the lake. Conductivity Site 3 (MS4) after the confluence with Colletts Road Drain (and its catchment effects) has been chosen as the monitoring site (Figures 4-12 and 4-14). This site is easier to access than Site 2 but still includes Colletts Road Drain. Site 4 (SQ30976 at The Lake Road) is monitored quarterly by ECan. Site 3 has no historical data, but the principle of monitoring as close as possible to the discharge point to give more accurate flow and load data is the reason to choose Site 3. It is suitable for cultural assessment. The cost-effectiveness of monitoring a new site in reasonably close proximity to a site with historical data will require further research to validate this choice.

Boggy Creek was not originally included in the programme, but it falls within the top nine (eighth equal) for weighted attributes, has high public interest, has several improvement initiatives and was used for stream augmentation in 2015.

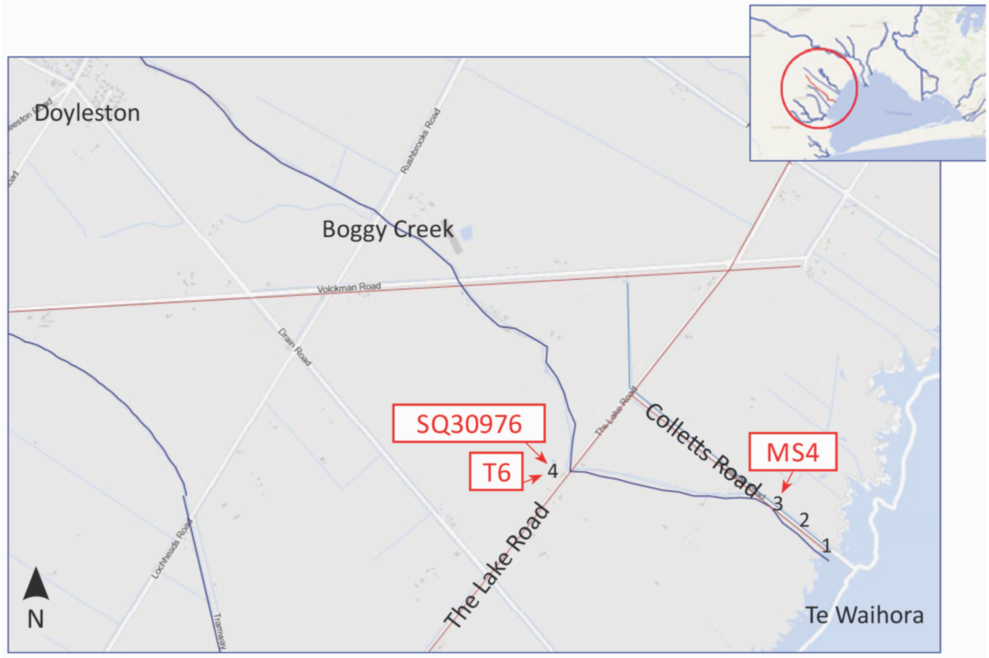
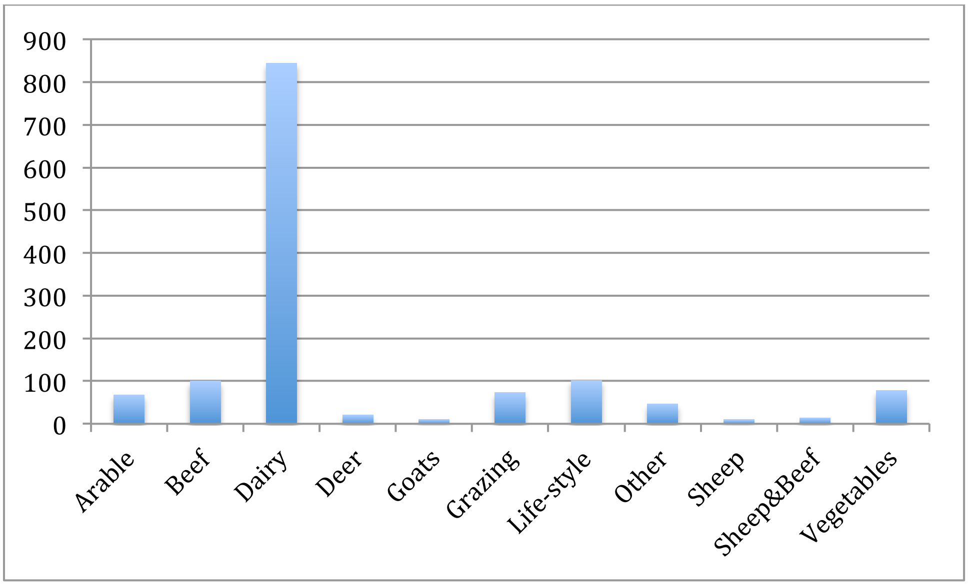


Figure 4-12: Boggy Creek showing location, conductivity sites 1 to 4 (as per Table 4-5), programme monitoring site (MS4), ECan (SQ30976) and CPWL (T6) monitoring sites (compiled from Canterbury Maps 2016). Map scale approximately 1 cm to 400m.

Table 4-5: Boggy Creek conductivity (μS/cm) survey showing temporal and spatial readings (2016).

		March	June	Oct
Lake level		0.70	1.10	0.64
Lake open/closed		closed	closed	open
Wind		NNE-20	no wind	SW-24
Flow (m^3/s) at site 4		0.016	0.087	0.041
Sites	m from lake			
0	*10*	923		
1	*200*	282		
2-DOC notice	*370*	283	365	360
3	*500*		323	
4-Lake Road	*1400*	321	402	496



Figures 4-13: Land use areas (ha) in Boggy Creek catchment (1503 ha).

(Compiled from Agribase data, 2015).

Figure 4-14: Boggy Creek at monitoring site MS4.

Monitoring Site 5 (MS5): Selwyn River

The Selwyn River is a rain-fed river, rising in the foothills of the Big Ben Ranges of the Southern Alps, with losing and gaining reaches. It is primarily spring-fed as it reaches Te Waihora. It is approximately 97 km in length and is physically the largest tributary of Te Waihora. It contributes between 5% and 30% of the inflow (Table 2-5). The median flow is approximately a third of the mean flow (Table 4-12). The hill-fed headwaters are decoupled from the lower reaches for much of the year creating a variable and intermittent flow (Figure 4-15) ranging from zero to 10 m^3/s, or to extremely large floods (Figure 4-18b), which can add a significant water volume and load to the lake, albeit intermittently (ECan, 2011). Downstream of the Main South Road, the spring-fed streams and catchments of Silverstream, McRaes Drain, Snake Creek and Baileys Creek/Miles Drain add a significant amount of water to the lower reaches (ECan, 2006). The river and its tributaries change in character (depth and width), becoming braided near Coes Ford, until they become channelized as they flow towards the lake. The catchment area of the Selwyn is 18 267ha. Sheep and beef dominate land use (Figure 4-17). The pressures on this tributary are water quantity, wide-ranging land use (but little dairy effluent spreading) and climate change.

The Selwyn River is particularly significant for recreational use and is monitored, during summer, for swimming at several upstream sites. *State of the Lake* water quality grade is poor at Coes Ford, but invertebrate grade is good (Lomax et al., 2015) The Selwyn and its tributaries are considered by Golder Associates (2012) as moderate for ecological values. The Selwyn River has a water level recorder at Coes Ford, just west of the concrete ford and close to a piped culvert entering from the southern side.

The conductivity survey (Figure 4-16 and Table 4-6) carried out to establish the most upstream effects of the fresh water/lake water interface showed the Selwyn to be very dependent on the level of the lake and the effects of wind. A large turbid plume travelling upstream was obvious as the lake level rose (Table 4-8). This plume moved inland for approximately 4000 m. The conductivity data agreed with anecdotal advice from Selwyn River residents. A possible monitoring site between the Selwyn Upper Huts and Coes Ford (7260 m from the discharge point into the lake) was abandoned when all the parameters required for robustness, longevity, safety and cost were considered. A third to half of the 7260 m is flanked by lake flat and DOC land, as the river has formed a birds-foot delta into Te Waihora. Silverstream is a significant tributary, discharging into the Selwyn approximately 550 m upstream of Coes Ford. This tributary has a large catchment (Snake/McGrath/Silverstream 1497 ha) and on two visits to the area, before and following the drought period (in 2016–17), the Silverstream tributary appeared to be contributing a significant (60% to 80%) flow at its confluence site. This Silverstream catchment has had several surveys carried out to try to determine the source of increased *E. coli* and nutrient levels. Baileys Creek/Miles Drain (catchment area 1002 ha) flowing from the catchment area north of Silverstream (Figure 4-16), discharges into the Selwyn approximately 400 m downstream from Coes Ford and at this confluence, this tributary appeared to be contributing another 30% towards the total river flow; (however, this is contrary to Clark (2011), who states that Miles Drain has been known to be dry while the Selwyn flowed). A long-term gauging survey would need to be carried out to confirm actual flows. The Baileys catchment has similar land use to the Silverstream/Snake catchments but is not captured in any current monitoring (routine ECan monitoring is done at Coes Ford).

To achieve the objectives of the monitoring programme for Te Waihora, the site that fulfils some of the criteria required (flow and load) is downstream of the confluence with Baileys/Miles Drain (Site 7, Figure 4-16). This site is, under base flow conditions, safe, easily accessible and practical for all aspects, and has been chosen as MS5 (Figure 4-18) but has no historical data. Historical data since 1958 relates only to Coes Ford (ECan SQ30916).

The accurate estimation of total load for the Selwyn poses many problems, as during summer the flow may be ephemeral for significant stretches of the river. However, if climatic conditions change, rainfall, particularly from the northeast, can cause increased flows or large floods, as previously noted. A specific survey would be necessary to determine correlations between sites. Other factors affecting load to be considered in association with a site change, are the cost-efficiency factors to attain robust data when flood flows are not yet a part of routine calculations. Best use of resources may be to continue to use Coes Ford as the monitoring site and establish monitoring of flood loads, sediment and other more weighty priorities. Additional factors for consideration are that monitoring for human recreation is carried out at Coes Ford. Sites 6 and 7 are both suitable for cultural assessment.

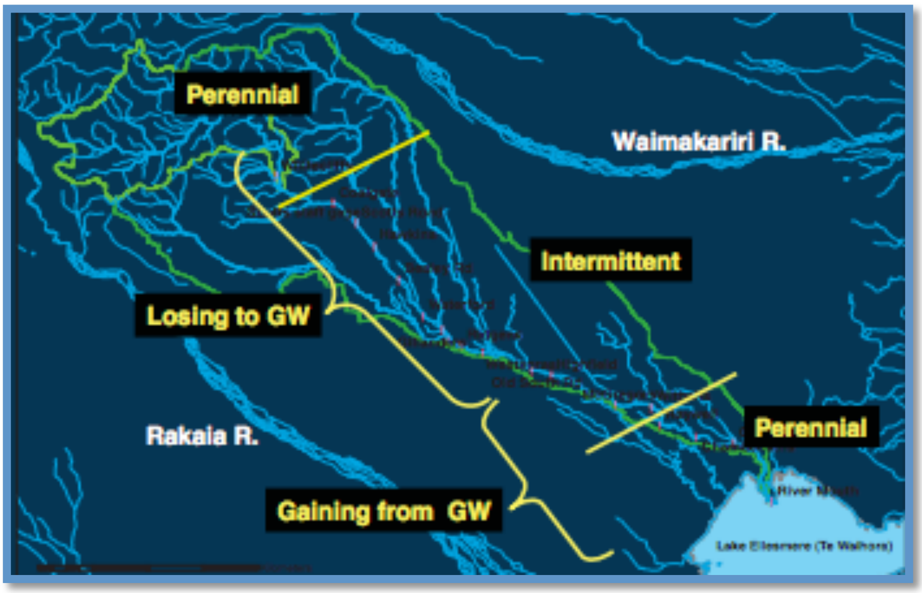


Figure 4-15: Selwyn River catchment (outlined in green) showing hydrological patterns and flow types (Lomax et al., 2015)

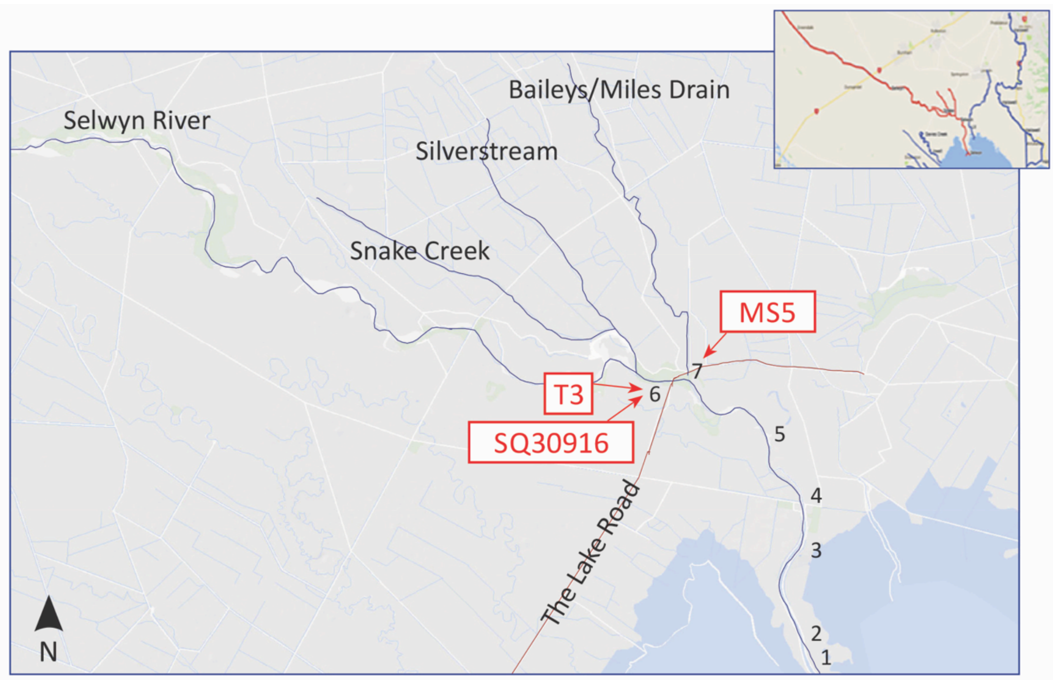


Figure 4-16: Selwyn River showing location, conductivity sites 1 to 7 (as per Table 4-6), programme monitoring site (MS5), ECan (SQ30916) and CPWL (T2) monitoring sites (compiled from Canterbury Maps 2016). Map sale approximately 1 cm to 1.3 km.

Table 4-6: Selwyn River conductivity (µS/cm) survey showing temporal and spatial readings (2016).

		March	May	June	August	Sept	Oct
Lake level		0.70	0.77	1.10	0.80	0.96	0.64
Lake open/closed		closed	closed	closed	closed	closed	open
Wind		NNE-20	NW-strong	no wind			SW-24
Flow (L/S) at Site 6-Coes Ford		0.14	0.5	0.39	0.42	0.42	0.39
Sites	**m from lake**						
0	*0*						
1	*550*	9,950				10,510	380
2	*750*	9,470					
3-lower huts	*3240*	2,180					262
4-upper huts	*3820*	328	314	930		310	264
5	*4820*						264
6-Coes Ford	*7260*	253	281	269	276	276	262
7	*6860*						**262**

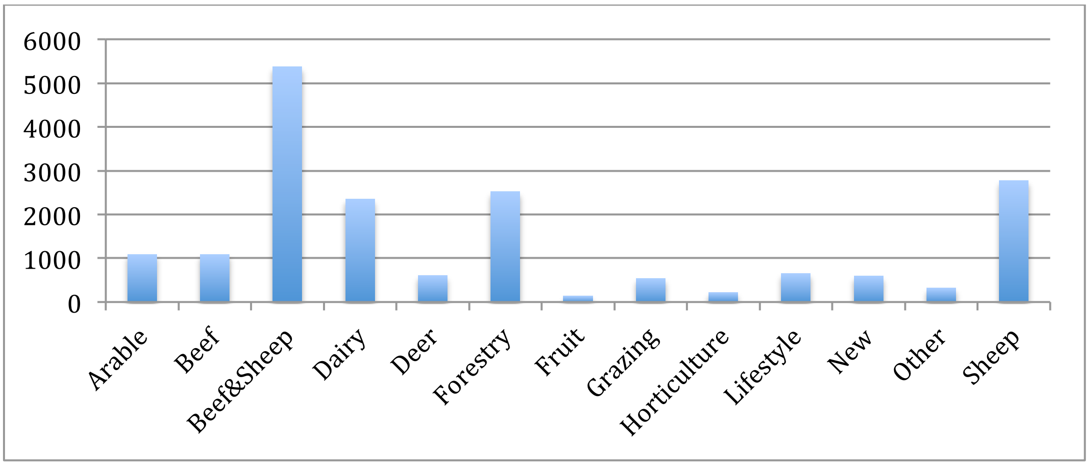


Figure 4-17: Land use areas (ha) in Selwyn River catchment (18 267 ha). (Compiled from Agribase data, 2015).

Figure 4-18a: Selwyn River at monitoring site 7 MS5 (2016).

Figure 4-18b: Selwyn River in flood, Leeston Road bridge, July, 2017

Monitoring site 6 (MS6): L II River

The L II River has the largest consistent flow (and possibly largest base flow load) currently discharging into the northern boundary of Te Waihora. It is a highly modified waterway and was primarily a drain for former swampland, but has some natural streams as well as drains, with a very consistent flow from most of its tributaries (Figure 4- 19). The L I Creek rises from springs north of the township of Lincoln and is joined by the spring-fed Liffey to become the L II River. Springs Creek joins the L II some 500 m downstream. The L II contributes up to 29% of the inflow. The L II has traditionally been maintained by SDC as part of the drainage system, to carry out this function to enable farming within its catchment. High groundwater levels are common in this area. The catchment area is 2900ha and land use (Figure 4-20) for cattle is greater than 50% (dairying and beef combined), with associated dairy effluent spreading consents. Ecological values range from low to high. Native fish are found in many areas (Golder Associates, 2012).

Although the L II has many straight channels, it is a priority area for environmental enhancement and riparian planting as per WET (Rennie, 2012). The L II flows towards the lake through Yarrs Lagoon, intensive farmland and through lake flat before it discharges into Te Waihora. *State of the Lake* (Lomax et al., 2015) water quality grade is poor (site at Pannetts Road, SQ30878).

The L II is downstream of the townships of Rolleston and Lincoln and the Lincoln Drainage system. The pressures on this tributary are numerous, ranging from possible increased intensification of land use, increasing population, increasing pressure on water quantity, possible point-source pollution and climate change. Lincoln Village promotes environmental awareness through many community activities and has an active Lincoln Envirotown Trust promoting sustainability and environmental awareness in association with other Te Waihora stakeholders (Lincoln Envirotown Trust, 2017).

Access close to Te Waihora created difficulties for the conductivity survey (Figure 4-19 and Table 4-7) to establish clearly the fresh water/lake water interface. The preferred monitoring site (Site 1) at Wolfes Road (1570 m from the lake) is the closest site to Te

Waihora (Figure 4-19). It is safe, representative and accessible and has been chosen as MS6 (Figure 4-21). There is ECan data for Site 1 from 1984 to 2014. There was some anecdotal comment that the lake water might affect this site, but on investigation, the conductivity on 11 June 2013 when Te Waihora had the highest lake level (1.81 m) since 1941, was 227 μS/cm, and conductivity in this survey ranged from 220 to 250 μS/cm. These data confirmed the fresh water/lake water interface to be downstream of the Wolfes Road site, but research to establish a reason for ECan to stop monitoring at this site will need to be established. The Pannetts Road site (Site 2, and 3760 m from lake, shown in Figure 4-19) is currently the monitoring site for ECan but is upstream of the confluence with Powells Road Drain (on the east of the road), which has a significant catchment area. MS6 at Site 1 (Figure 4-19) is the preferred site to achieve the objectives of this monitoring programme, but will require further validation. It is suitable for cultural assessment.

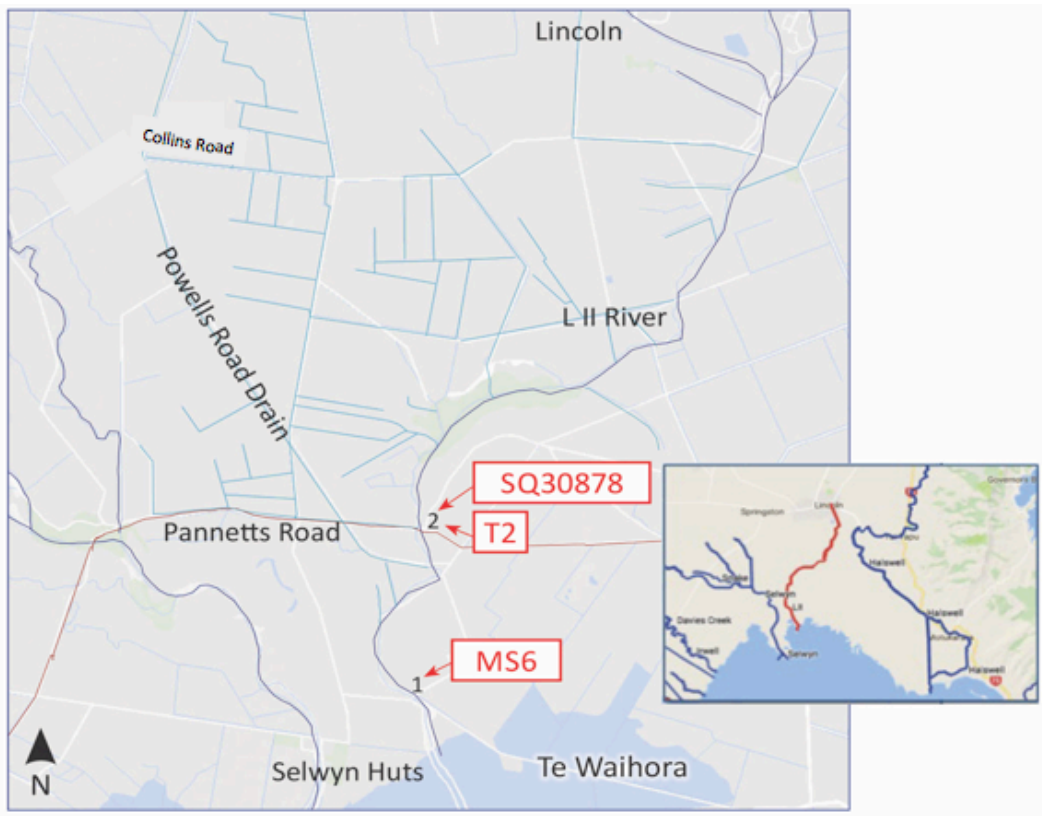


Figure 4-19: L II River showing location, conductivity sites 1 and 2 (as per Table 4-7), programme monitoring site (MS6), ECan (SQ30878) and CPWL (T2) monitoring sites. Drains are shown as lighter blue (compiled from Canterbury Maps 2016). Map scale approximately 1 cm to 800m.

Table 4-7: L II River conductivity (μS/cm) survey showing temporal and spatial readings (2016).

		March	May	June	August	Sept	Oct
Lake level (m)		0.70	0.77	1.10	0.80	0.96	0.64
Lake open/closed		closed	closed	closed	closed	closed	open
Wind (km/hr)		NNE-20	NW-strong	no wind			SW-24
Flow (m3/s) at Site 2		1.147	1.915	1.944	1.73	2.404	1.87
Sites	**m from lake**						
1-Wolfes	*1570*	231	241	228		247	220
2-Pannetts	*3760*	227			205	250	226

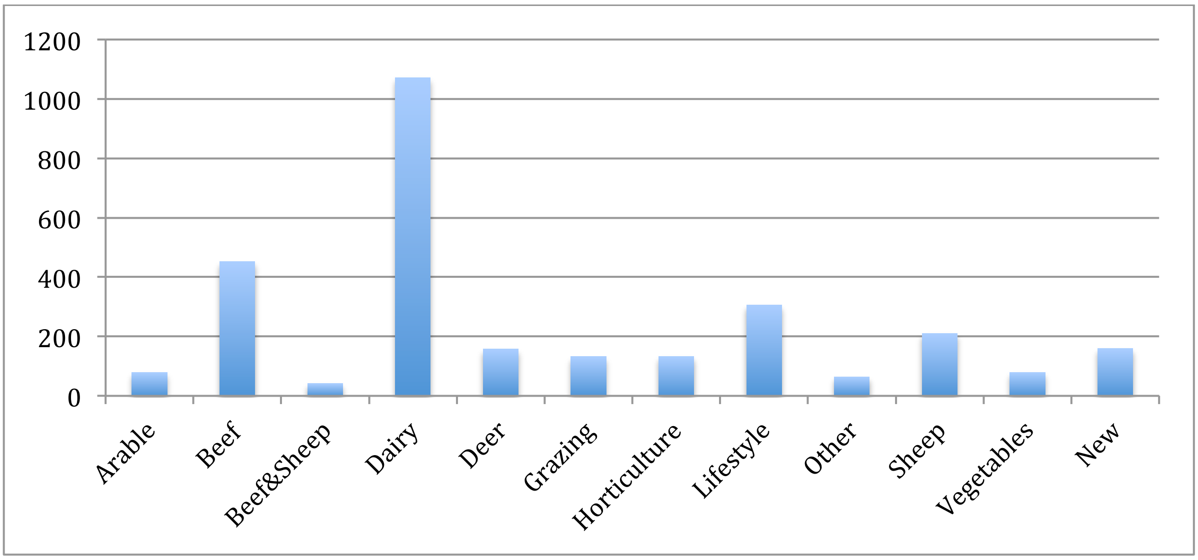


Figure 4-20: Land use areas (ha) in L II River catchment (2 900 ha). (Compiled from Agribase data, 2015).

Figure 4-21: L II River at monitoring site MS6 (2016).

Monitoring site 7 (MS7): Halswell River

The Halswell River (Figure 4-22) rises in the Christchurch suburb of Halswell where the Nottingham Stream drains heavy soils, and is joined to the south by Knights Stream (and its tributary Marshes Road Drain), draining the industrial area of Hornby. Dawson Creek and numerous drains and small streams join the Halswell River including several flowing from the foothills of Banks Peninsula. The Halswell River then meanders through more rural areas around the hills of the peninsula draining primarily farming land. It is highly modified in all its reaches, but in particular, as it approaches Gebbies Valley, where a canal has been constructed to drain directly into Te Waihora. The Old Halswell River continues to meander around the foothills and joins the canal just before it discharges into the lake. The Halswell River contributes approximately 10% of the inflow to Te Waihora. The catchment area is 16 520 ha. The Halswell River has a water level recorder at Tai Tapu. The siting of the recorder at Tai Tapu does not give an accurate indication of the discharge into Te Waihora (due to the effect of rainfall on Banks Peninsula) for flows only moderately above its base flow, as previously noted by ECan (2013).

Ecological values for the Halswell River are moderate (Golder Associates, 2012). There are several native fish species found in many of the tributaries as well as in the main body. Many areas within the catchment have had riparian planting and stream fencing carried out. *State of the Lake* (Lomax et al., 2015) water quality grade is poor (site at McCartneys Bridge, SQ32872). The pressures on this area are urbanization with increasing population (SDC, 2016b), land use intensification with significant areas of dairying and cattle grazing (Figure 4-23) and climate change.

As the lower reaches of the Halswell River are very low-lying, many of the possible monitoring sites in close proximity to the lake are affected by the fresh water/lake water interface, shown by Figure 4-22 and Table 4-10. All accessible sites on the Old Halswell River were found to have high conductivities. The only accessible site (Site 1 and 1000 m from the discharge point) in close proximity to the lake discharge, is affected by the lake water. The next possible site (Site 2 and 4000 m from the discharge point) is the corner of Duck Pond Road and Ridge Road (Duckpond Road Bridge). Sampling has good vehicle access, but gauging and sampling require a high level of safety, as the river is steep-sided and deep. This site has some historical data. It is not the current ECan monitoring site (Site 8, McCartneys Bridge, River Road SQ32872 and 11 000 m from the discharge point) but is monitored monthly by CPWL (T1) (Figure 4-22). It is downstream of a number of streams draining Banks Peninsula valleys and several farm drains. It gives a more accurate picture of the water quality discharging into Te Waihora. This site is linked to the water level recorder at Tai Tapu (14 500m upstream) to calculate flow, so will require gauging at Duckpond Road Bridge. The overview and weighting for all aspects of monitoring for Te Waihora is to choose Duckpond Road Bridge (Site 2) as the routine monitoring site (MS7) to capture load into Te Waihora (Figure 4-24). It is suitable for cultural assessment.

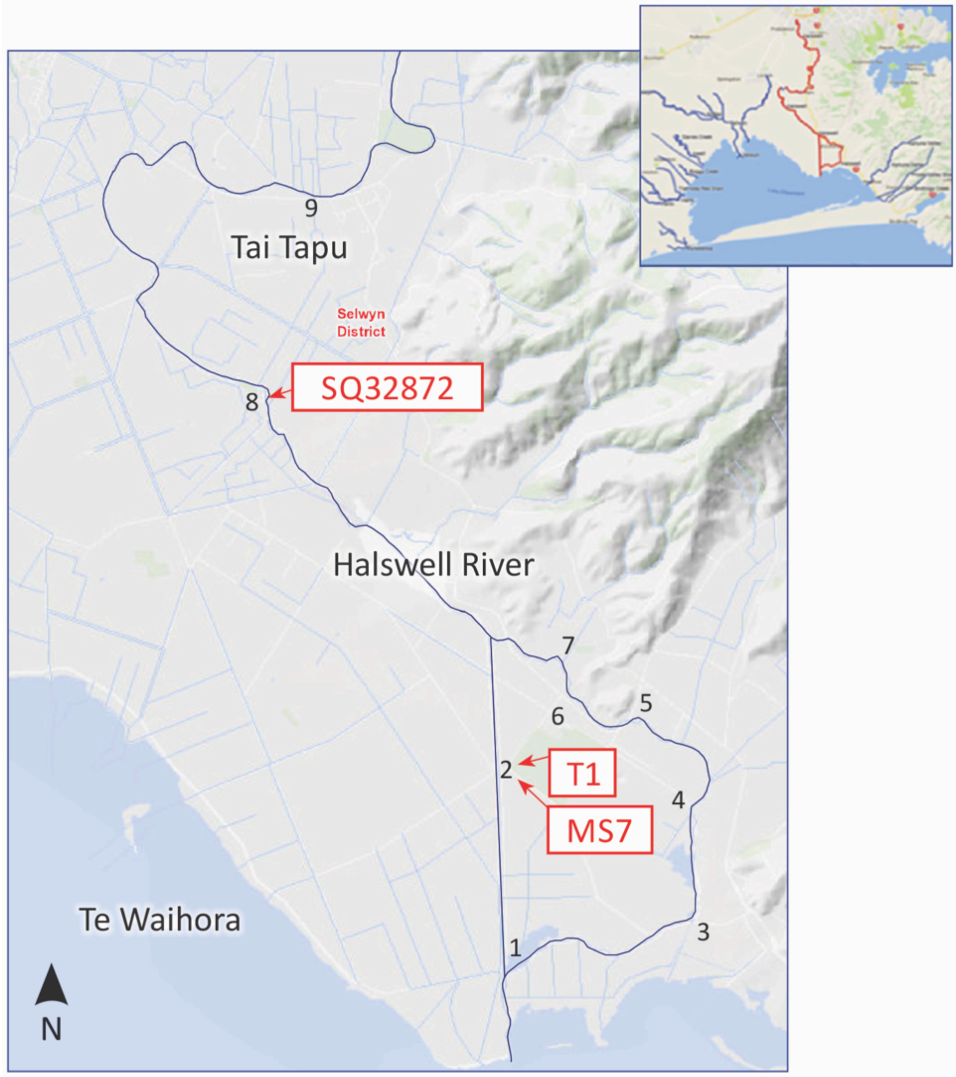
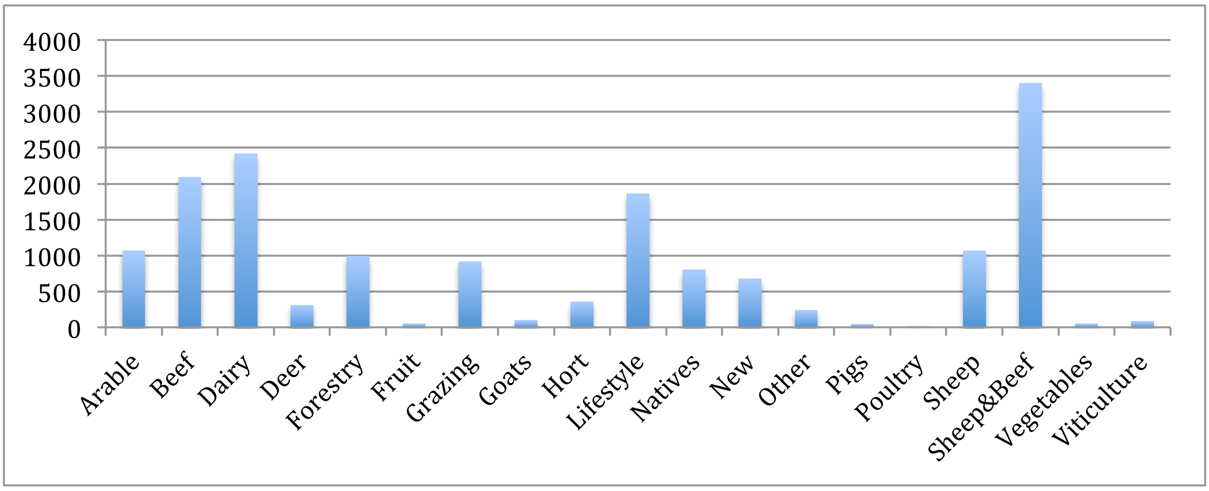


Figure 4-22: Halswell River showing location, conductivity sites 1 to 9 (as per Table 4-8), programme monitoring site (MS7), ECan (SQ32872) and CPWL (T1) monitoring sites(compiled from Canterbury Maps, 2016). Map scale approximately 1 cm to 1.1 km.

Table 4-8: Halswell River conductivity (µS/cm) survey showing temporal and spatial readings (2016).

		March	May	June	Sept	Oct
Lake level		0.70	0.88	1.10	0.96	0.64
Lake open/closed		closed	closed	closed	closed	open
Wind		NNE-20	SSW-22	no wind	S-42	SW-24
Flow (m^3/s)site 8		0.36	0.4	0.62	0.58	0.58
Sites	m from lake					
1-canal(crane)	*1,000*	1,411		350	379	
2-canal(Duckpd)	*4,000*	257	278	280	279	267
3-old Halswell	*800*	10,440				
4-old Halswell	*2,800*	5,550				
5-old Halswell	*7,710*	1,510	920			
6-old Halswell	*10,000*	858				
7-old Halswell	*10,500*	1,200				
8- McCartneys[a]	*11,500*	233	247		246	247
9-Tai Tapu	*18,500*	246	248		274	241



Figures 4-23: Land use areas (ha) in Halswell River catchment (16,520 ha) (Compiled from Agribase data, 2015).

Figure 4-24: Halswell River at MS7 (2016).

Monitoring site 8 (MS8): Kaituna River

Banks Peninsula is a peninsula of volcanic origin, which forms the north eastern edge of Te Waihora. The Banks Peninsula streams flow from the southern faces of Mt Herbert (919 m) and Mt Bradley (855 m) into what is known as Kaituna Lagoon on the eastern side of Te Waihora. The rivers are initially steep but meander across an area of lake flat before discharging into Te Waihora. These rivers experience high flows during rainfall events, but may revert to very low flows or no water for long periods particularly during summer. The flat area in close proximity to the lake has numerous ephemeral drains discharging to the lake. The high elevation, southerly aspect and volcanic geomorphology may cause erosion of the stream banks during high rainfall. Gebbies Valley streams and McQueens Valley streams primarily discharge into Te Waihora via the Halswell canal and drains (Figure 4-25). Both Kaituna Valley and Prices Valley streams were considered for monitoring as difficulty was found finding a suitable accessible site.

The Kaituna River is typical of the Banks Peninsula streams described above. It flows for approximately 16 km with several tributaries joining it, the main one being the Okana Stream. Due to the volcanic loess soils, the turbidity and sediment of the water is high during, and for some time following, rainfall events, resulting in potentially high dissolved-phosphorus levels. The Kaituna River contributes from 3% to 8% of the Te Waihora inflow. The catchment is 4197 ha. There is a water level recorder 4000m from the lake discharge at Site 2 (Figure 4-26).

Ecological values for Kaituna are high, with large areas of native vegetation on steep valley slopes (Golder Associates, 2012). *State of the Lake* (Lomax et al., 2015) water quality grade is fair at the current monitoring site (SQ30872) but very good in the upper reaches of the Kaituna River..

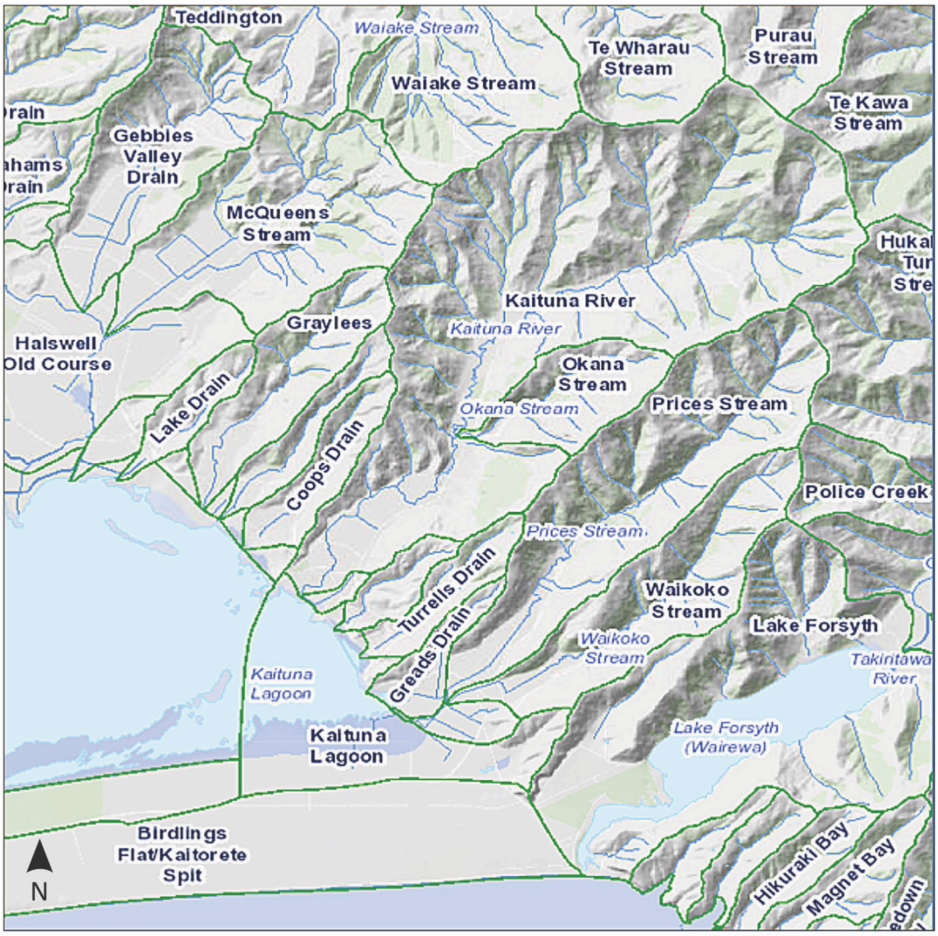


Figure 4-25: Banks Peninsula Catchments (Canterbury Maps, 2017). Map scale approximately 1 cm to 2 km.

Land use is predominantly beef and dairy in both Kaituna and Prices Valleys (Figures 4-27 and 4-28). The Kaituna River is monitored as indicative or moderately typical of the Banks Peninsula streams.

A site in the lower, flatter reaches of the Kaituna River is preferable, but several possible sites monitored for conductivity in this area showed lake water influence and enquiries for publicly available sites were not found. In order to ensure longevity for the monitoring programme, a site on public land is desirable. The freshwater/lakewater interface survey (Figure 4-26 and Table 4-11) confirmed the lake water influence problem. The recorder site (Site 2 and 4000m from lake discharge, SQ30782) is a considerable distance from Te Waihora. This site does capture land use on the higher hills and the water quality of the stream itself, but does not reflect diffuse or point-source pollution in the lower catchment (Figure 4-26). This site has historical data available, is safe, ensures longevity, is suitable for cultural assessment and is the site used by ECan for their monitoring.

The Prices Valley Stream has the same weighed aggregate score as Boggy Creek. It discharges approximately 1% of Te Waihora inflow but is less than one-third of the discharge of the Kaituna River. This inflow may be significant to the Kaituna Lagoon ecosystem during high rainfall and flood events. The catchment size is 1826 ha. A convenient and safe monitoring site is evident (Site 2 and 2380m from discharge) at a more optimum distance from Te Waihora; this is representative of this upper and lower catchment, but the catchment and flow are considerably smaller than Kaituna, spatially, Kaituna is representative of this area, Prices Valley Stream has the smallest inflow of the top nine and for these reasons it has not been chosen. The WET-*State of the Lake 2014-15* invertebrate grade for the Upper Prices Valley Stream is poor and the Lower Valley Stream is also poor (Lomax et al., 2015).

The Kaituna River recorder site (Site 2) has the advantage of historical data and a larger catchment area. The recommendation for MS8 is Site 2 (ECan routine monitoring site SQ30782, shown in Figure 4-29). This site is suitable for cultural assessment.

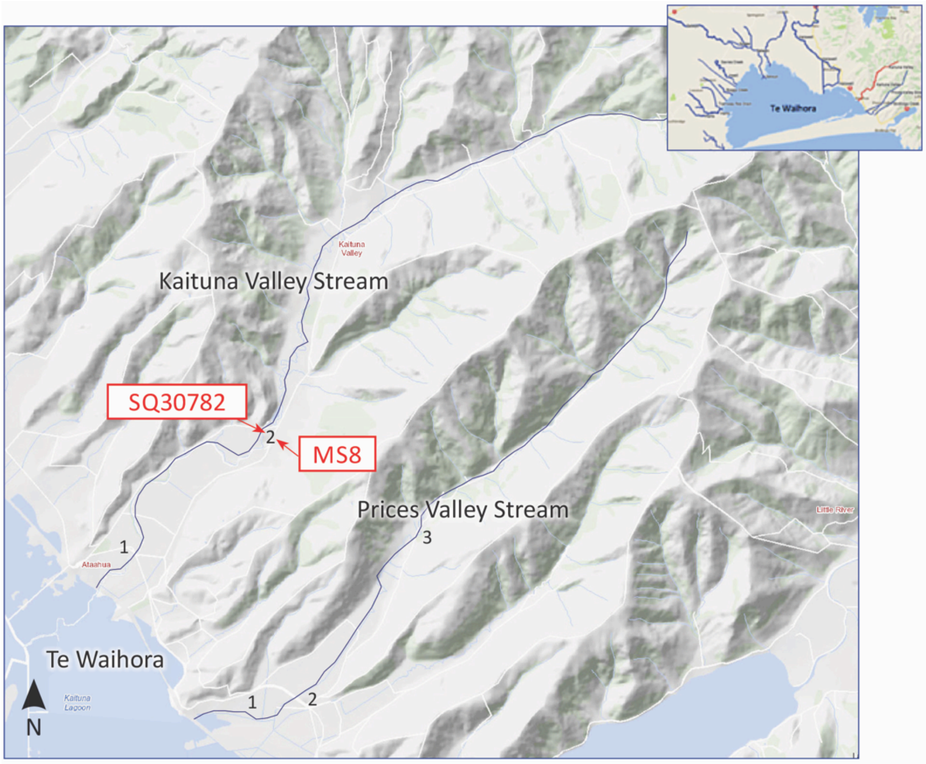
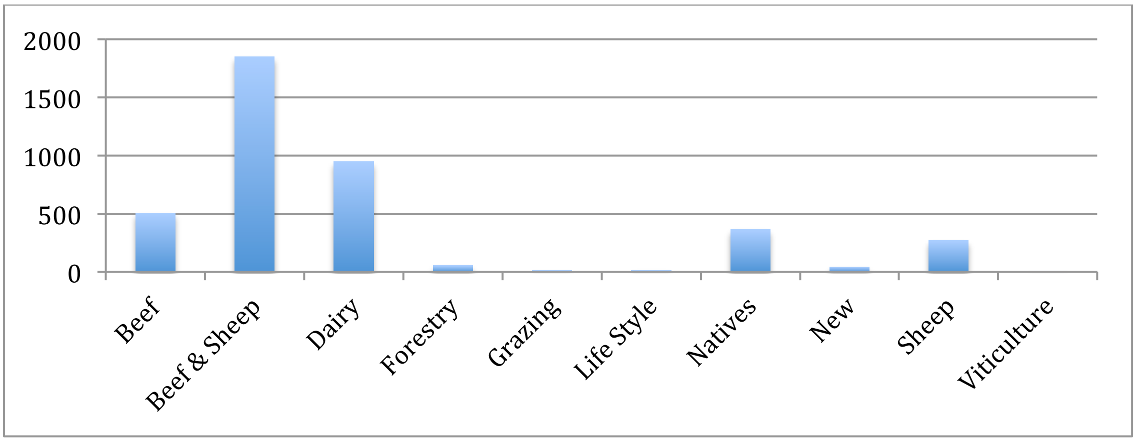


Figure 4-26: Kaituna Valley Stream showing location, conductivity sites 1 and 2 (as per Table 4-9), programme monitoring site (MS8) and ECan monitoring site (SQ30782) (compiled from Canterbury Maps, 2016). Map scale approximately 1 cm to 1.5 km.

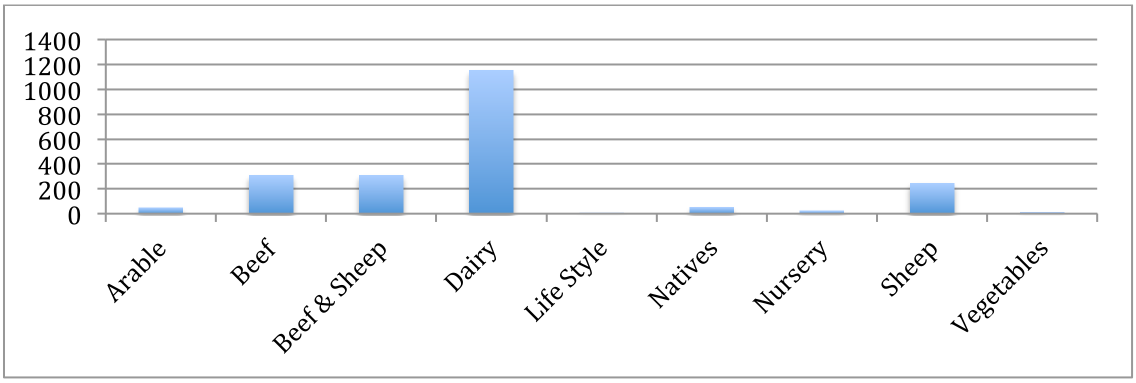
Table 4-9: Kaituna and Prices Valley Streams conductivity (µS/cm) survey showing temporal and spatial readings (2016).

		March	May	June	Sept	Oct
Lake level		0.7	0.77	1.1	0.96	0.64
Lake open/closed		closed	closed	closed	closed	open
Wind		NNE-20	NW-strong	no wind	SW-42	SW-24
Sites	m from lake					
Kaituna Stream						
Flow(m^3/s) at Site 2		0.041	1.914	0.159	0.325	0.64
1	*975*	2,700			882	159
2	*4,000*	227	229[a]	181[a]	161[a]	141[a]
Prices Valley Stream						
1	*60*	14,270	29,000			
2	*2,380*	186	209	170	172	149
3	*5,550*	182				

[a]-ECan data



Figures 4-27: Land use areas (ha) in Kaituna Valley Stream catchment (4197 ha) (Compiled from Agribase data, 2015).



Figures 4-28: Land use areas (ha) in Prices Valley Stream catchment (1846 ha) (Compiled from Agribase data, 2015).

Figure 4-29: Kaituna River at monitoring site MS8 (2017).

4.3 Lake site selection-application of criteria

The lake water quality monitoring sites are chosen to safely and reliably allow sampling for the NPS-FM (2014) parameters as well as those specific for Te Waihora (as per the main monitoring programme objective), (sections 2.3.2-lake sites and 4.1). Tributary discharge and lake water balance (as noted in Table 2-4 as necessary for comprehensive water quality assessment) are considered when selecting possible lake sampling sites. The NPS-FM (2014) requirement of a water quality sampling site to be representative of the "freshwater management unit" to detect spatial variability, requires at least one sampling site to relate to each 'unit' or area (Criterion 1). Figure 4-30 shows the location of the proposed sampling sites and Table 4-10 shows a summary of how they meet the set criteria, which is discussed in more detail in 4.3.1.

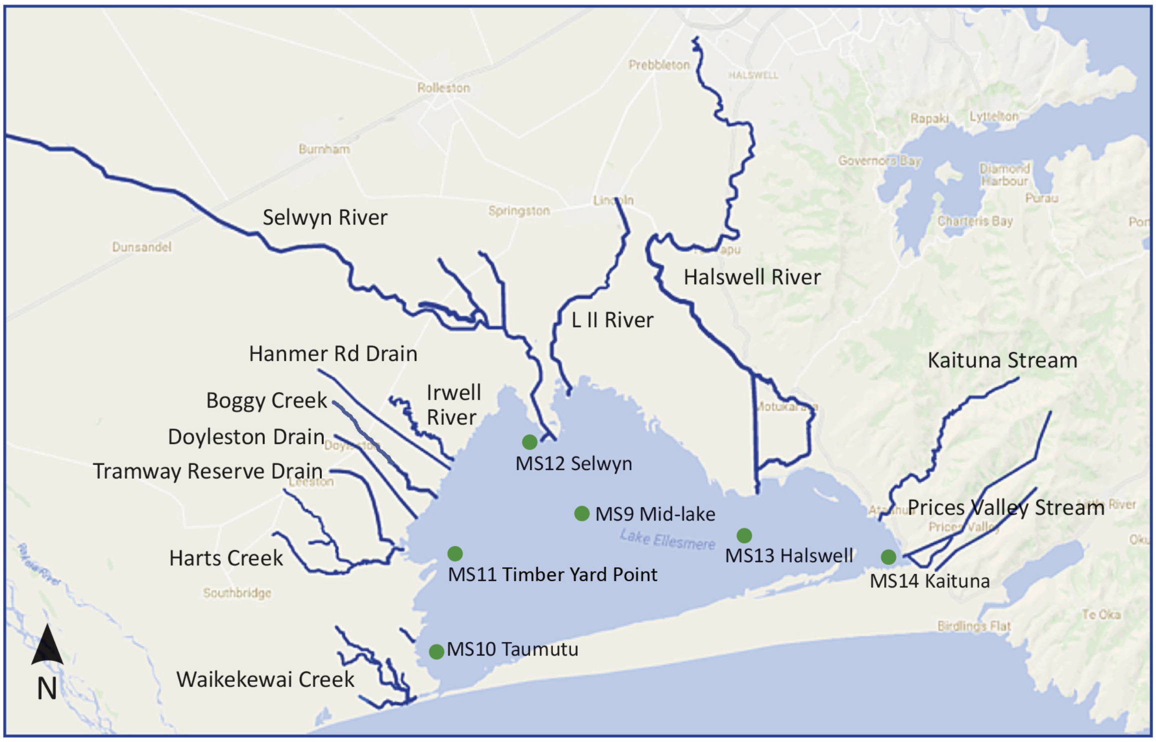


Figure 4-30: Location of proposed lake monitoring sites. Map scale approximately 1 cm to 4 km.

Table: 4-10: Application of the lake site criteria to the sampling sites.

			Criteria 1	2	3	4
Lake Site	easting	northing	representative	access & safety	historical data >5 years	NPS-FM & CLWP compliance
Mid-lake	1556068	5151907	yes	✓	yes	✓
Taumutu	1554459	5155719	yes	✓	yes	✓
Timberyard	1550578	5145424	yes	✓	yes	✓
Selwyn	1551391	5150721	yes	✓	yes	✓
Halswell	1563960	5151255	yes	✓	no	✓
Kaituna	1572937	5150829	no	✓	yes	✓

4.3.1 Lake monitoring sites

Monitoring site 9 (MS9): Mid-lake

This mid-lake site should monitor cumulative effects of the tributary inflows, seawater overtopping, general climatic conditions (e.g., wind) and the natural processes within the lake (Figure 4-30). All lake site criteria can be satisfied at this site. ECan routinely monitors this site (SQ30954) for the monthly parameters (Table 3-1) and additionally this site has a probe/telemetry system (Figure 4-31) communicating continuous data for DO (top and bottom), pH, turbidity, salinity, temperature, electrical conductivity, chlorophyll *a,* and *phyococyanin.* This lake site has significant historical data since 1983 (necessary for state and trend assessment) and is frequently quoted when overall lake water quality is referred to.

Figure 4-31: The mid-lake monitoring station owned and operated by ECan in Te Waihora (photo: ECan, 2016).

Monitoring site 10 (MS10): Taumutu

The Taumutu in-lake site encompasses all criteria but with particular emphasis on the effects of the opening/closing regimes, where salinity as well as suspended sediment will rise and fall. The overtopping of sea water (and resulting increase in salinity) will also be detected at this site. This site is representative of the area in close proximity to the opening/closing cut (Figures 4-30 and 4-32).

ECan monitor this site as part of their monthly sampling (SQ30956) and historical data since 1983 is available (Table 3-1). ECan also have a continuous monitoring station on the spit side of the lake outlet. All NPS-FM (2014) and local requirements are met. However, particular care regarding safety is needed in adverse weather conditions (as at all lake sites). This site has significant cultural importance due to its proximity to Ngāti Moki Marae. MS10 (shown in Figure 4-30) is located east of the trees that can be seen in Figure 4-32. The proximity to the sea and the small inlet/lagoon can also be seen near this site.

Figure 4-32: Lake opening to the sea. MS10 is the closest site (www.wet.org.nz).

Monitoring site 11 (MS11): Timberyard

The Timberyard monitoring site will capture the effects of natural lake processes as well as the water quality effects of all activities in Harts Creek catchment and the east-flowing tributaries/drains and their catchments. Due to its proximity to the outflow of any possible point-source pollution, this site would be in the correct position to detect any sewage pollutants from the Leeston Sewerage Scheme or the possibility of *emerging* *contaminants* in that sewage. Many water recreation activities are common at this site such as boating, water-skiing, swimming or fishing. Additionally, several macrophyte establishment initiatives and sediment stabilisation research projects are being carried out in this area (NIWA, 2015). This site (SQ30953) is also part of ECan's monthly monitoring programme (Table 3-1). Historical data since 1985 is available from this site.

Monitoring site 12 (MS12): Selwyn

This site off the mouth of the Selwyn River is to the south of the birds-foot delta and monitors the effects of inflows from the Selwyn River and its catchment. Due to the changing inflows into Te Waihora (Table 2-5), in order to ensure it is representative of this lake area, it may be necessary to monitor water quality in a more northerly position in closer proximity to the L II, as this river may discharge the largest volume in the future. The prevailing winds are commonly from the south or east, which would tend to blow the currents away from this monitoring site, however a survey may need to be carried out to ascertain any effects from changes in water inflow. These changes should be addressed during the monitoring programme's regular review. This site (SQ30955) is part of ECan's monthly monitoring programme (Table 3-1). Historical data is available at this site since 1983. The water quality from all tributary catchments may show the effects of urban, industrial or intensive farming activities.

Monitoring site 13 (MS13): Halswell

This sampling site has been proposed to comply with the predetermined criteria, in particular the requirement of spatial representation and detection of pollutants (specifically from the Halswell tributary), to achieve the pre-set criteria. The Kaitorete Spit and Kaituna Lagoon area are under the local authority of Christchurch City Council and many improvement initiatives have been proposed as part of the Stormwater Management Plan (CCC, 2015). The Kaitorete Spit area (directly south of the sampling point) is highly important for wildlife (Ford et al., 2017) and is noted to be of national botanical importance (ECan, 2002), while the north-eastern fringe of the lake has many ephemeral drains (which have no monitoring associated with them) discharging directly into Te Waihora. Some water quality testing has been carried out by ECan in the area of Osborne's Drain (2011 and 2012) and south of the Halswell River mouth (1990), but no regular testing is done. The routine sampling point at Kaituna Lagoon (MS14) is very close to the lakeshore and while achieving the objectives for that local area does not monitor the water quality in the greater contiguous lake water.

The inclusion of an additional lake sampling point may require a considerable amount of research (initially desktop analysis) followed by the cost-effectiveness of the information gained, in particular, to the amount of data already available from the current sampling sites. The fundamental question of *why,* will need to be clearly addressed. Additionally, the exact location of the sampling point would need to be established. A position closer to the Halswell inflow may be more appropriate, or a position near the 'fragile' ecological habitat of the fringes along Kaitorete Spit where the effects of large numbers of wildfowl would be apparent, (this area is home to several endangered species), or a point mid-way representative of both aspects.

Monitoring site 14 (MS14): Kaituna

The monitoring site in this area is in a position to detect changes in water quality in the area close to the lakeshore only. This site (SQ33593) is part of ECan's monthly monitoring programme (Table 3-1). Historical data since 2009 are available and comparisons can be made with the data from the tributaries flowing from Banks Peninsula. There is a large wetland area adjacent to this part of Te Waihora, which has unique bird-life and habitat affecting the water quality.

4.4 Parameter selection- application of criteria

Parameter choice has been made based on pollutant sources, regulatory requirements, data use and specific requirements of Te Waihora, all previously outlined.

The dissolved major ions (calcium to sulfate) noted in Table 2-6, do not align cost-effectively with the criteria specific to Te Waihora and add little relevant information so they have not been included in this programme. The criteria set out in Chapter 2 are applied to all common parameters (Table 4-11). Additionally, the parameters for ecosystem health (e.g., DIN, VSS) which have historically been monitored, and have been shown to play important roles within the ecological systems (Highton, 2014;

Larned & Schallenberg, 2006; Schallenberg et al., 2010) have been included to ensure robust data is available for future requirements.

In the Canterbury catchment, there are two indices commonly used for water quality reporting: trophic level index (TLI, see section 1.5.3) and water quality index (WQI). The parameter requirements for the calculation of these indices are therefore included in the parameter selection.

TLI

Quantification of water quality in lakes has historically been done using the trophic level index (TLI; Burns et al., 2000). The TLI is defined as the life-supporting capacity per unit volume of a lake (Burns et al., 2000) and is commonly used as an indicator of the health of a lake in New Zealand. It is constructed by combining transformations of several parameters, which do not necessarily change in the same direction. This results in a composite index describing the nutrient enrichment.

There are two versions of TLI in New Zealand—TLI3 and TLI4 (Burns et al., 2000; Verburg et al., 2010). The TLI3 index is derived from log-transformed concentrations of chl *a*, TN and TP. TLI4 adds the Secchi depth figure as well. Secchi depth was not available for all sites in New Zealand and was found to make very little ultimate difference, resulting in TLI3 being the accepted method for eutrophication grading including regular reporting for Te Waihora (MfE, 2017a).

The CWMS and Te Waihora *State of the Lake* reports use the TLI3 index to show this value using a colour-coded traffic-light system to convey simple information (ECan, 2015; Lomax et al., 2015).

WQI

This index was developed by ECan to describe the overall condition of the water and to summarize water quality data into a single number (ECan, 2017a). It is based on a Canadian system and uses three factors: scope (the number of parameters not meeting water quality objectives), frequency (the number of times these objectives are not met), and amplitude (the amount by which the objectives are not met). The parameters needed for this are:

- nitrate and nitrite nitrogen (NNN) for toxicity
- dissolved inorganic nitrogen (DIN) for effects on periphyton and macrophyte growth

- dissolved reactive phosphorus (DRP) for effects on periphyton and macrophyte growth
- ammoniacal nitrogen for toxicity
- total suspended solids (TSS) for clarity and sediment
- *E. coli* for recreation

As with TLI, a traffic-light coloured system has been developed to convey information on WQI grade.

An area of debate is the aspect of clarity/turbidity/sediment and the different ways these parameters can be measured. Initially all three will be included but this should be reviewed at an appropriate time.

Table 4-11: Criteria attributes for considered parameters.

Criteria	1	2	3	4	5	6
	regulatory requirements	use of data	specific pressures	historical data	inter-dependencies	cost effective
water discharge(recorder)		✓	✓	✓		✓
water discharge(gauging)	R	✓	✓	✓		✓
lake level		✓	✓	✓		✓
Parameters						
temperature	R	✓		✓	✓	✓
pH		✓		✓	✓	✓
electrical conductivity		✓		✓		✓
dissolved oxygen	R	✓		✓	✓	✓
clarity/secchi disc		✓	✓	✓		✓
turbidity		✓	✓	✓		✓
total suspended solids		✓	✓	✓		X
volatile suspended solids		✓	✓	✓		X
dissolved organic carbon				S		X
nitrate plus nitrite	R	✓	✓	✓	✓	✓
ammoniacal nitrogen	R	✓	✓	✓	✓	✓
total nitrogen	R	✓	✓	✓	✓	✓
dissolved reactive phosphorus	R	✓	✓	✓	✓	✓
total phosphorus	R	✓	✓	✓	✓	✓
Chorophyll a	R	✓	✓	✓		✓
E Coli	R	✓	✓	✓	✓	✓
copper		✓		S		Y
lead		✓		S		Y
zinc		✓		S		Y
cadmium			✓	S		Y
emerging contaminants		✓		S		Y
PAH		✓		S		Y

Key: ✔-fulfills criterion, R- regulatory requirement, Y- yearly, S- some data available, X-does not meet criteria

4.4.1 Parameter choice

The selection of parameters for a water quality monitoring programme requires an understanding of the pressures and their associated effects within the local catchments (Bartram and Balance, 1996). Any point-source discharges have been outlined in Chapter 1, as have the effect of anthropogenic land use, increasing irrigation and diffuse pollution.

Tributary discharge

The flow rate of rivers/streams is a foundational parameter for interpreting results and calculating loads and needs to be reported for all surface water quality sites. Streams can present a challenge to any monitoring programme while base flow (gauging or a water level recorder) may be a routine measurement, storms and flood flows are more challenging. The state of the water body (i.e. base flow or flood conditions) is not easily perceived from many reports. This is a part of the monitoring programme that may need further development (see recommendations in Chapter 5), as sediment load is an important parameter for Te Waihora. Research has been carried out on sediment measurement techniques (Ballantine et al., 2014) and storm chasing for determining storm loads for example, in large catchments (McKergow & Davies-Colley, 2010) and in New Zealand (Ballantine and Davies-Colley, 2013).

Lake water level

Recording lake water level and lake status (i.e., open/closed) at the sampling time are essential. Because Te Waihora is an ICOLL, the state of the lake (open/closed) is an overarching control on salinity and water level, and is therefore relevant to data interpretation and lake management.

Temperature

Water temperature is a function of flow, depth, insolation and air temperature. It will vary seasonally, locally and diurnally. The temperature of the water affects the functioning of aquatic ecosystems as well as the physiology of the biota (Kelly et al., 2014). Reaction rates (biochemical and chemical) increase markedly with increase in temperature, gas solubility decreases while mineral solubility often increases. Respiration and growth rates of aquatic organisms increase or decrease with temperature, and most organisms will compete, reproduce and function effectively only within a specific range. Temperature also affects the sensitivity and resilience of organisms to parasites, toxic waste and diseases (Ballantine et. al., 2014). Temperature effects may be direct (changes in the metabolism) or indirect through a change in the solubility of oxygen or toxicity to ammonia (ANZECC, 1992).

Some water quality parameters are temperature dependent (for example, conductivity, DO) so that reports for a particular parameter must always state the temperature. Temperature of the water *in situ* is a standard parameter but because water temperature changes diurnally, routine sampling (particularly for trend analysis) should be carried out at the same time of day. Maintaining sample integrity (for temperature) from site to laboratory is essential for valid results of many parameters. To ensure a robust programme, the effect of temperature on a parameter may result in its exclusion or inclusion (e.g., if samples cannot reach the laboratory within a specified time frame).

Water clarity, turbidity and suspended solids

Clarity, or conversely turbidity, is due to suspended particles (tiny clay particles, silt, phytoplankton, small organic particles) in the water column. The most significant impact of these sediments is the reduction of light penetrating in the aquatic systems (Pennington & Cech, 2010). These total suspended solids (TSS), also called suspended particulate matter (SPM), may silt up the streambed, smother habitats of invertebrates and fish, or become a reservoir for nutrients and bacteria (Ryan, 1991). Pollutants (e.g., phosphorus, metals, bacteria, pesticides) may also attach to particles increasing the pollutants in a receiving water body. Consequently, sediment may be a pollutant in its own right, or a vector for other pollutants (Ballantine et. al., 2014).

Visual clarity, turbidity and total suspended sediment (TSS) are related parameters, but are measured in different ways. For clarity, a Secchi disc (8-inch disc with alternating black and white quadrants) can be lowered into the water until invisible- the distance being a measure of the clarity of the water. Another similar method to measure clarity in shallow water is the clarity tube (1 metre long, 50 mm diameter clear acrylic tube, graduated along its length in centimetres) which, when viewed from one end, will give a similar clarity value. The typical laboratory method to measure turbidity, is a nephelometer (using the scattering of light through the water against Formazin standards) to determine the turbidity of the sample; this gives results in nephelometric units (NTU). Total suspended solids (TSS) and volatile suspended solids (VSS) (e.g., phytoplankton) use gravimetric methodology.

All these measurement techniques have mutual relationships (Ballantine et al., 2014), which should be considered in the planning of routine monitoring. If a correlation between one method and another is to be used (e.g., converting turbidity to TSS), the particular composition of the sediment (fine silt, or algae) causing the turbidity is essential to determine for each specific water body. The recent review by ECan proposes replacing turbidity with Secchi disc measurements (Kelly et al., 2014), while Hughes et al. (2014) propose using turbidity as a proxy for fine sediment (with light attenuation, *E. coli* and TP), but for the management of Te Waihora, it is particularly important to know and understand these relationships.

As previously emphasised, sediment is of major importance to Te Waihora as it is acknowledged as one of the main concerns in the eutrophication of the lake (Sagar et al., 2004). The lake's depth, the constant stirring of the lake sediment by the winds from several directions and the absence of macrophytes increase the importance of the parameters of TSS, VSS, clarity and turbidity. This is documented in the NPS-FM (2014) as a priority area for development because the ecosystem health is impacted in various ways by sediment attributes, which are not currently defined in the NPS-FM (2014). Further studies or surveys will aid this understanding and management for Te Waihora.
The calculation of TLI 4 uses the Secchi disc value, so is a compulsory parameter for many lake monitoring programmes, however TLI 3 (TN, TP, chl *a*) is the index used for Te Waihora .

pH

The pH value, is a measure of how acidic or alkaline the water is on a scale of 1 to 14. It is the negative logarithm to the base 10 of the hydrogen ion concentration. The pH of fresh water is usually between 6.5 and 8.2. pH may cause changes to, or may be changed by, other abiotic variables (Kelly et al., 2014). Aquatic ecosystems are affected by altering their ion exchange and acid-base balances. Extremely high or low pH will lead to the death of most aquatic species (ANZECC, 1992). Its value is dependent upon the water catchment geology and soils as well as anthropogenic activities and discharges. Banks Peninsula run-off streams exhibit chemical parameters indicative of volcanic soils. Changes or trends may indicate pollution. Being a simple relatively inexpensive parameter, pH measurement can be carried out on-site and may give critical information at certain times (e.g., it may indicate a flux of pollution). The measurement of pH may be carried out in situ as well as in the laboratory (NEMS, 2017a).

Electrical conductivity

Electrical conductivity is the ability of water to conduct an electric current. It is a function of the concentration of dissolved ions in the water and is temperature dependent. Conductivity will be a reflection of the geology and soils of the catchment area and will vary with flow. High levels of contamination (e.g., nutrients or metals) will increase conductivity. An environmental guideline value below 750 μS/cm (for periphyton growth) is recommended but trend analysis may be more useful in many circumstances. As with all measurements (but with conductivity especially) the reporting unit must be noted. The SI unit for conductivity is S/m at 25^{o}C. In New Zealand waters, the unit used is more commonly, microsiemen per centimetre (μS/cm) but reports will also use millisiemen per metre (mS/m).

Electrical conductivity is an inexpensive parameter, easily carried out on-site, with good accuracy and reliability. Conductivity, like pH, can give important information (particularly applicable for Te Waihora tributaries, where the fresh water/lake water interface detection indicates the actual water being tested) with very little extra cost.

Following a review in 2013, ECan recommend conductivity is carried out on-site, rather than as previously, in the laboratory (Kelly et.al., 2014).

Nitrogen

The main routes for nitrogen transfer within the catchment are generally (a) nitrate leaching, (b) direct inputs of animal excreta to streams, (c) transport of excreta by surface run-off, and (d) soil erosion (ECan, 2002). Nitrogen in water is in several different chemical species. Nitrate-N is the most common form of inorganic soluble nitrogen in the catchment area and is easily taken up by aquatic biota. Nitrite-N (NO_2-N) is generally present only in very low concentrations, unless pollution, e.g., from industrial waste, has occurred. NO_2-N is toxic to humans as well as to aquatic life. Ammoniacal-N (NH_4-N) is found naturally in low concentrations, but high concentrations can be highly toxic to aquatic ecosystems. It can be present in dairy effluent, sewage and industrial discharges. This toxicity varies with pH (e.g., the CLWRP levels for NH_4-N range from 2.57 mg/L at pH 6 to 0.18 mg/L at pH 9; ECan, 2017b). During sample transportation, species of nitrogen can change due to biogeochemical transformations (e.g., mineralisation of organic N, nitrification of ammonia).

For river monitoring, the NPS-FM (2014) amended 2017 (MfE, 2018) recommends TN, and dissolved inorganic nitrogen (DIN) (NO_3-N, NO_2-N and NH_4-N). Many New Zealand environmental monitoring programmes use nitrate and nitrite nitrogen (NNN) (NO_3-N and NO_2-N only) or occasionally total Kjeldahl N (organic N and NH_3-N), but this is seldom used currently. For lake monitoring, the NPS-FM (2014) recommends TN only.

For Te Waihora and its catchment, the concentrations and ratios of the nitrogen species differ between the tributaries and the lake body (section 1.5.3). Recent research led by Schallenberg (Schallenberg, 2017) and others, extends the understanding of N spatially and chemically within Te Waihora emphasising that data use is an important factor for N species selection.

TN is a component of the TLI calculation for lakes, so is a compulsory parameter to measure in lake water monitoring (MfE, 2018). WQI utilizes DIN requiring these forms to be monitored.

Phosphorus

Phosphorus (P) in surface water occurs naturally at low levels (but may be higher in volcanic areas, e.g., Banks Peninsula) depending upon geology, soil type, and season. It may be transported in soluble and particulate forms, with particulate P carried by soil particles and organic matter. Soluble P may be a mixture of dissolved forms and P attached to colloidal material that passes through the 0.45 µm filter. Phosphate (PO_4^{3-}) readily attaches to sediment and often enters waterways by run-off or bank erosion, with less direct leaching into aquifers than N. Phosphorus may show a strong relationship to TSS due to it sticking to the sediment particles. PO_4 is often referred to as dissolved reactive phosphorus (DRP) and is the P form most readily available for uptake by algae or aquatic plants. This form is most commonly monitored in rivers and streams. The NPS-FM requires DRP to be measured in rivers. Guideline levels in the Canterbury Land and Water Regional Plan (ECan, 2017b) specific to Te Waihora for spring-fed plains tributaries are 0.016 mg/L, and for Banks Peninsula streams, 0.025 mg/L. NPS-FM (2014) recommend TP for lake monitoring. TP is a component of the TLI calculation, so is a compulsory parameter for lake assessments (MfE, 2018).

Te Waihora has a legacy of phosphorus accumulated in the lakebed sediments (ECan, 2013). This is re-released into the lake particularly when wind-induced wave action stirs the lake sediments, and is a major problem for lake clarity. This internal phosphorus load is associated with phytoplankton blooms (toxin production, low DO, higher pH). To achieve the ZIP outcomes (section 1.6.1), this legacy phosphorus will need to reduce by 50% (ECan, 2013).

Dissolved oxygen

Dissolved oxygen (DO) is an essential element for a healthy and diverse aquatic ecosystem. DO is influenced by water velocity, organic material decomposition, aquatic plant respiration; it is temperature dependent and changes diurnally. Lack of shading affects DO especially in the summer in smaller waterways. It is expressed as mg/L or as percentage saturation. DO is a parameter recommended by NPS-FM. The CLWRP (ECan, 2017b) has differing acceptable levels for different situations: spring-fed plains and spring-fed plains–urban waterways: 70%, Banks Peninsula streams: 90%, WRRP minimum of 80% for CCC waterways.

Heavy metals

The effects of urban run-off into Te Waihora were studied in 2000 (Ray, 2000) showing that due to the relatively small areas of urbanisation at that time, there was little significant impact. However, as urban areas are expanding and heavy metals are elevated in urban drainage, this effect should be monitored at regular intervals. Urban run-off contains primarily copper from brake linings and other vehicle parts, lead from, e.g., paint, old petrol residues, zinc from tyres and galvanized iron, and polycyclic aromatic hydrocarbons (PAH) from fuel and oil.

Copper and other metals may also be a contaminant from agricultural sprays, dairy footbaths, or even palm kernel extract. Cadmium is a possible pollutant of importance in agricultural areas where cadmium-containing fertilisers (e.g., superphosphate) have been used. These metals need to be monitored over extended time periods to track any significant increases.

Chlorophyll *a*

Chl *a* is a specific form of chlorophyll used in oxygenic photosynthesis. It allows plants (including algae) to photosynthesize, that is, to use sunlight to convert simple molecules into organic compounds. Chl *a* is the predominant type of chlorophyll found in green plants and algae and as such is a measure of the amount of algae growing in a waterbody. However, chlorophyll *a* as a measure of phytoplankton biomass has been to shown to vary due to variable intracellular chl *a* concentrations, when in different light regimes or nutrient availability conditions (MacKenzie, 2016).

Chl *a* is used as part of the TLI3 index and as such is an essential parameter to monitor for lakes (MfE, 2018).

Escherichia coli

Escherichia coli (*E. coli*) are the bacteria most commonly used to indicate the presence of faecal pollution as they are found in the gut of all warm-blooded animals, hence are an indicator of the potential presence of this pollution. Enteric viruses, cysts, bacteria and parasitic protozoa (including pathogenic microorganisms such as *Campylobacter*, *Salmonella*, *Cryptosporidium* and *Giardia*) may all be present in faecal material. *E. coli* can indicate recent faecal contamination from human, wildlife or livestock origins.

Faecal contamination on farms is mainly from grazing livestock, although wild and feral animals and birds can be a source also, hence, faecal contamination into waterways may be direct or indirect, such as in surface run-off, subsurface flows or drainage (ECan, 2002).

Several guideline values are currently in use in New Zealand. The CLWRP Schedule S5A (ECan, 2017b) states that *E. coli* values should be less than 260 MPN/100ml for upland streams and less than 550 MPN/100ml for lowland and urban streams, for safe recreation. Ministry of Health Guidelines for recreational water quality are categorized from very low (<130 *E.coli* /100ml) to very high (>550 *E.coli* /100ml) (MfE, 2003).

NPS-FM (2014) requires monitoring of *E.coli* for rivers.

Emerging contaminants

'Emerging contaminants' (also known as contaminants of emerging concern), are synthetic or naturally occurring chemicals (or microorganisms) that may pose a risk to human health, ecology and the environment. Pharmaceuticals, personal care products, veterinarian products and endocrine disrupting compounds are among the prime examples. Their risks and effects are not currently well understood.

This is an area of importance to Te Waihora, particularly from a cultural and environmental perspective, given the increasing population and intensification of land use. However research into emerging contaminants is still being carried out by various institutions within New Zealand and worldwide to fully characterize their nature and effects, for example the USGS (USGS, 2017). Consequently this is a parameter group to review at regular intervals for validity and cost-effectiveness.

4.5 Sampling frequency selection- application of criteria

The criteria set out in Chapter 2 for sampling frequency, in order to detect temporal changes and allow particular trend analyses, have been applied in this monitoring programme. Firstly, it is recognised that not all parameters require monitoring at the same frequency due to the fact that some parameters may be presence/absence (and may require further monitoring or research), while others must be sampled meticulously (i.e. same site, same time of day, same frequency time frame) to identify valid temporal trends, hence a number of parameter and frequency "suites" have been compiled.

The regulatory requirements of the NPS-FM,2014 amended 2017 (MfE, 2018) and CLWRP (ECan, 2017b) dictate some of the environmental parameters for routine trend analysis (e.g., NO_3-N, DRP), however the same parameter may require a different frequency when a different objective is studied (e.g., the effect of wind on in-lake TSS or the condition of lake water when the lake is "open").

4.5.1 Frequency choice

For routine environmental change and trend monitoring, the regulatory frequency of sampling is monthly, but the requirements of surveys, specific programmes or recommendations may dictate other specific frequency requirements dependent on the use of the data. Some parameters are able to utilize probes and telemetry to give continuous data readings at some sites, e.g., within the lake, for specific data requirements. Other situations such as flow and load require a more complex sampling and timing system. This may be continuous for a set time following a trigger water level, which would initiate the monitoring of Suite 4 (Table 4-14).

Table 4-12 shows stream discharges into Te Waihora and the tributaries where flow changes significantly following rain events. The ratio of the flow mean to the flow median (the last column in Table 4-12) gives an indication of tributaries most affected by rainfall events. Ratios significantly greater than 1 indicate where flood monitoring is most important (i.e. Kaituna, Selwyn and Waikekewai). Further research and surveys will be required to establish whether all tributaries should be monitored in flood events, or only those where significant flood loads are established.

Table 4-13 shows frequency attributes considered against the criteria. Criterion 2, the use of data (the *why* for monitoring that site) is paramount for frequency selection. Similarly Criterion 6 (in conjunction with Criterion 2), cost-effectiveness, must be addressed for each frequency selection. Table 4-14 shows the parameter and frequency suites for the proposed programme.

Table 4-12: Stream discharge into Te Waihora
(adapted from CPWL, 2015 and ECan historical data up to 2015).

Tributary	7D MALF (l/s)	Mean flow (l/s)	Median flow (l/s)	Annual volume (Mm^3)	Flow permanence (%)	Ratio of mean to median
Waikekewai	4	111	43.7	3.5	92.9	2.5
Harts Creek	560	1696	1191	53.5	100	1.4
Boggy	0.3	188	109	5.9	79.4	1.7
Selwyn	289	2976	963	93.9	99.5	3.1
L II	1,050	2307	2170	72.8	99.8	1.1
Halswell	500	1186	1034	37.4	99.7	1.1
Kaituna	44	478	108	15.4	99.5	4.4

Table 4-13: Criteria attributes for considered frequencies.

	Criteria				
	1	2	3	4	5
Frequency	regulatory	use of data	flow and load	lake status	pollution
monthly	✓	S	X	S	S
yearly		S	X	S	S
high flows		S	✓	S	S
continuous		S	✓	S	S

Key: ✓-fulfills criterion, S-specific to parameter and data use, X-does not fulfill criterion.

Additional to analysis of the water for the following parameters, as noted previously, the climatic conditions at the time of sampling as well as the status of the lake (open/closed) will aid in report interpretation.

Table 4-14: Parameter suites and their frequency.

Parameter Suite 1: tributaries	Parameter Suite 2: lake
Frequency: monthly	Frequency: monthly
flow	lake level
temperature	temperature
dissolved oxygen	dissolved oxygen
pH	pH
electrical conductivity	electrical conductivity
turbidity	turbidity
total suspended solids (TSS)	total suspended solids (TSS)
ammoniacal nitrogen	volatile suspended solids (VSS)
oxidized nitrogen (NOx)	Secchi disc
total nitrogen	ammoniacal nitrogen
dissolved reactive phosphorus	oxidised nitrogen
total phosphorus	total nitrogen
E. coli	dissolved reactive phosphorus
	total phosphorus
	Chlorophyll *a*
	E. coli

Parameter Suite 3: tributaries and lake
Frequency: 1 to 5 yearly
emerging contaminants
heavy metals-copper, lead, zinc, cadmium.
polyaromatic hydrocarbons (PAH)

Parameter Suite 4: tributaries-high flow conditions
Frequency: triggered by predetermined flow threshold, then for storm duration
flow
turbidity
total suspended solids
total nitrogen
total phosphorus

Chapter Five – Discussion: Implementation of an integrative water quality monitoring programme

5.1 The proposed water quality monitoring programme

The proposed integrative water quality monitoring programme for Te Waihora is summarized in Figure 5-1 and Tables 5-1 and 5-2. This proposed programme meets the criteria chosen for tributary and site choice, parameters to be tested and frequency of sampling for routine testing. The programme integrates some of the routine monitoring carried out by ECan and consent monitoring by other stakeholders (e.g., CPWL), with new monitoring to achieve the objectives of this programme for Te Waihora. Additional to the monthly monitoring for the routine parameters, it includes monitoring for flood events and for emerging contaminants, selected heavy metals and polyaromatic hydrocarbons (PAH), (which may extend from one to five years dependent upon results or any changes in climatic or anthropogenic conditions). As noted in Chapter 3, the monitoring for localized improvement initiatives is not included.

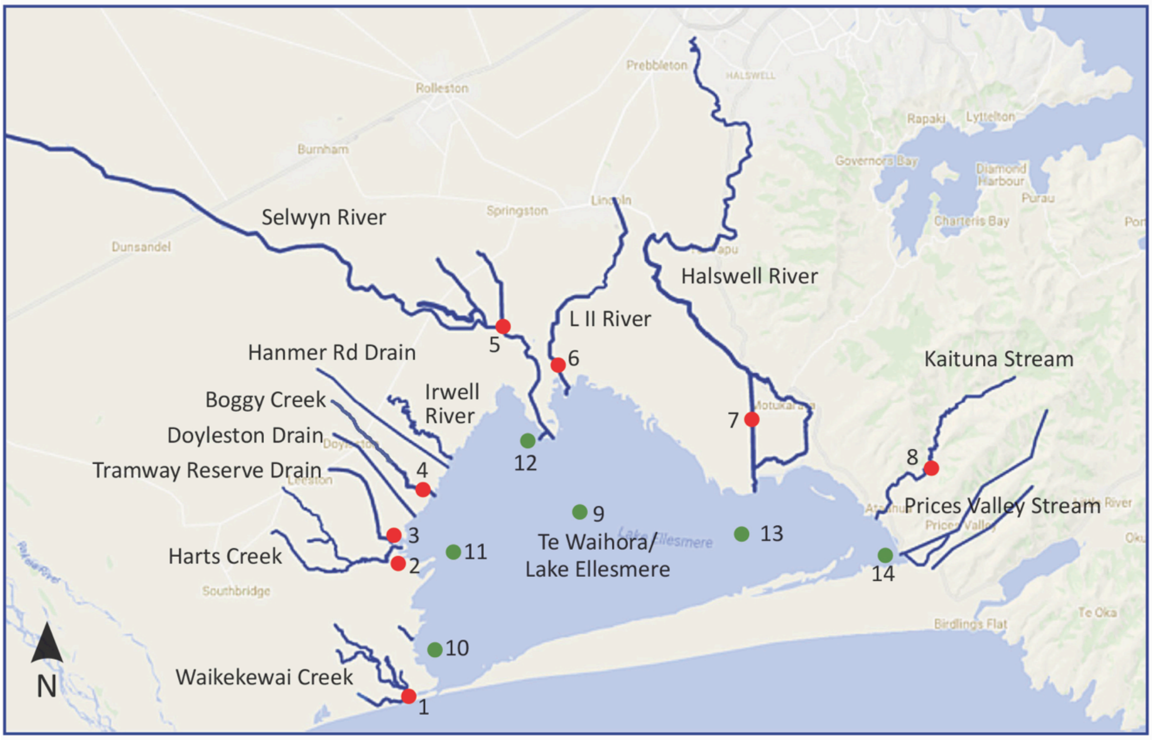


Figure 5-1: Te Waihora and the lower catchment showing monitoring sites (1 to 14) for the integrative water quality monitoring programme. Tributary monitoring sites are shown in red, lake monitoring sites are shown in green.

Table 5-1: Monitoring site locations.

Tributary sites	easting	northing	**Lake sites**	easting	northing
1 Waikekewai	1548481	5143654	9 Mid-lake	1556068	5151907
2 Harts	1546793	5150435	10 Taumutu	1554459	5155719
3 Tramway Reserve Road	1546961	5151563	11 Timberyard	1550578	5145424
4 Boggy Creek	1549267	5153817	12 Selwyn	1551391	5150721
5 Selwyn	1553018	5161648	13 Halswell	1563960	5151255
6 L II	1555704	5160191	14 Kaituna	1572937	5150829
7 Halswell	1565402	5157696			
8 Kaituna	1574438	5155128			

Table 5-2: Monitoring programme parameters, site types and frequencies.

	Parameters, discharge, lake level	Site types	Frequency
Suite 1	flow, pH, temp, cond, DO, clarity, turb, TSS, NO_2-N, NO_3-N, NH4-N, TN, DRP, TP, *E. Coli*	tributaries	monthly
Suite 2	lake level, pH, temp, cond, DO, turb, TSS, VSS, Secchi, NO_2-N, NO_3-N, NH_4-N, TN, DRP, TP, chl *a*, *E. Coli*	lake sites	monthly
Suite 3	flow, lake level, emerging contaminants, Cu, Pb, Zn, Cd, PAH	all sites	1-5 yearly
Suite 4	flow, turbidity, TSS, TN, TP	tributaries	high flow conditions

5.2 Differences in the proposed and current monitoring programmes

As outlined, the most cost-effective way to implement the proposed monitoring programme is to integrate the relevant current monitoring carried out by different stakeholders as summarised in Tables 5-3 and 5-4, and to include (if possible) further new sites or parameters into the existing monitoring, with additional responsibilities for monitoring by current or new parties. The differences between the proposed monitoring programme and existing monitoring programmes, as shown in Tables 5-3 and 5-4, will require further surveys or research to validate any significant site change or the addition of a new tributary, frequency or parameter. Please note that there has been no contact or consultation with ECan, the current monitoring stakeholders or any new parties at this time.

Table 5-3: Comparison of the proposed programme sites and their monitoring frequency with that of current monitoring programmes in the lower catchment. Differences between the proposed programme and current routine monitoring are shown in blue. The parameters measured by stakeholders are shown in Table 5-4.

	Proposed monitoring			Current monitoring			
Tributary	site	m to lake	frequency	ECan	CPWL	m to lake	frequency
Waikekewai	MS 1	300	monthly	SQ34540		900	monthly
Harts Creek	MS 2	1280	monthly	SQ30992	T8	1,280	monthly
Tramway Reserve	MS 3	500	monthly				
Boggy Creek	MS 4	500	monthly	SQ30976	T6	1,400	quarterly
Selwyn River	MS 5	6,860	monthly	SQ30916	T3	7,260	monthly
L II	MS 6	1,570	monthly	SQ30578	T2	3,760	monthly
Halswell	MS 7	4,000	monthly	SQ32872		11,500	monthly
					T1	4,000	monthly
Kaituna	MS 8	4,000	monthly	SQ30782		4,000	monthly
Lake	site		frequency	ECan			frequency
Mid-lake	MS 9		monthly	SQ30954			monthly
Taumutu	MS 10		monthly	SQ30956			monthly
Timberyard	MS 11		monthly	SQ30953			monthly
Selwyn	MS 12		monthly	SQ30955			monthly
Halswell	MS 13		monthly				
Kaituna	MS 14		monthly	SQ33593			monthly

5.2.1 Identification of site coverage and gaps

New sites:

The proposed programme would include two new sites, Tramway Reserve Drain Road Drain and Halswell in-Lake Site (shown in blue in Table 5-3). Doyleston Drain quarterly monitoring by ECan would not be included in the integrative programme.

Change in the site on already-monitored tributaries:

The Waikekewai Creek, Boggy Creek and Selwyn River monitoring sites have relatively small changes (the distance from the lake discharge) from those used by routine ECan monitoring. Differences in distances to the lake are shown in blue in Table 5-3. These sites will require robust validation to substantiate a change to the currently monitored sites (which have continuous data). The L II monitoring site for the proposed programme is the same as the ECan monitoring site until 2014, when monitoring at this site ceased.

Research into this aspect will need to be carried out. The Halswell River is monitored by CPWL at the Duckpond Road Bridge (T1). As noted, all changes will need validation to justify inclusion in this integrative method of a more accurate way to monitor the Te Waihora water quality.

Table 5-4: Comparison of the parameters and frequency with current monitoring programmes. Differences between the proposed programme and current routine monitoring are shown in green.

	Tributaries			Lake	
Parameters	Proposed Integrative programme	CPWL monthly	ECan monthly	Proposed Integrative programme	ECan monthly
temperature	x	x	x	x	x
pH	x	x	x	x	x
electrical conductivity	x	x	x	x	x
dissolved oxygen	x	x	x	x	x
clarity/secchi disc	x	x	x	x	x
turbidity	x	x	x	x	x
total suspended solids	x		x	x	x
volatile suspended solids				x	x
nitrate plus nitrite	x	x	x	x	x
ammoniacal nitrogen	x	x	x	x	x
total nitrogen	x	x	x	x	x
dissolved reactive phosphorus	x	x	x	x	x
total phosphorus	x	x	x	x	x
chorophyll *a*				x	x
E. Coli	x	x	x	x	x
copper	Y			Y	
lead	Y			Y	
zinc	Y			Y	
cadmium	Y			Y	
PAH	Y			Y	

Key: X parameter tested monthly, Y parameter tested yearly

5.2.2 Identification of parameter coverage and gaps

New parameters:

Heavy metals (Cu, Pb, Zn, and Cd), PAH and emerging contaminants of concern have been included in the integrative programme to be monitored on a 1 to 5 yearly basis, dependent upon the regular review and any relevant research. There is some historical data available.

The integrative programme will also include monitoring for flood events for flow, turbidity, TSS, TN and TP. This aspect will require further research and debate to confirm the number and identification of sites, as well as the “stakeholder organisation” to carry out the monitoring.

Change in parameters:

The proposed integrative programme would utilize CPWL monthly monitoring for site MS7 (Halswell River). TSS is not routinely measured by CPWL (shown in green in Table 5-4), thus a solution to address this will need to found.

5.2.3 Identification of frequency coverage and gaps

New frequency:

Sediment within Te Waihora is identified as one of the major problems for the lake, but it is an area where there is no routine monitoring when a flood or high rainfall event occurs. Parameter Suite 4 is a part of the integrative programme to be carried out when the water level recorders reach a predetermined level. Harts Creek, Selwyn River, L II River, Halswell River and Kaituna River have recorders while the recorder in Doyleston Drain could be used, or additional research carried out to validate the construction of a recorder in Boggy Creek. Some research has been done in this area (e.g., Oliver, 2013), which could be continued, following appropriate funding.

Change in frequency:

All routine sites are monitored monthly except Boggy Creek (blue in Table 5-3), which would change from quarterly to monthly. This addition will require consultation to validate.

The proposed surveys/research to validate site, parameter and frequency changes to the tributaries, will give a clearer picture of the water quality discharging into Te Waihora and where any gaps still exist. The additional site within the lake (once validated) will also show more clearly the effects of the contiguous drains/tributaries for catchment management purposes.

One aspect to keep paramount is quality control for all aspects, for all stakeholders. Surveys to validate the inclusion of data from “new” or additional stakeholders or service providers, will need rigorous confirmation to ensure the robustness of all areas of the water quality testing (as per NEMS, 2017a & 2017b).

5.3 Recommendations to fill the gaps

Actions to address the differences between current monitoring and the integrative programme could be to:

1. Approach Waterways Centre for Freshwater Management for a staff/student study to carry out an initial validation of the site changes for the Waikekewai Creek, Boggy Creek and Selwyn River and the cost-effectiveness and validity of including the new tributary of Tramway Reserve Drain as part of the integrative programme.
2. Undertake desktop research to find why the ECan monitoring of the L II River site at Wolfes Road (MS6) ceased.
3. Approach LU/UC for the validation of the inclusion of the in-lake site of MS13 (Halswell).
4. Approach ECan and the current monitoring agencies (e.g., CPWL) to change or add sites, parameters and frequencies to their monitoring programmes. Actual sites, parameters and frequencies are dependent on 1 to 3 above.
5. Undertake research to carry out a cost analysis for additional monitoring and deletions of existing monitoring if these are found to be valid.
6. Approach LU/UC to include in the university teaching curriculum the sites that cannot be added to the routine monthly integrative monitoring programme by current monitoring.
7. Approach Whakaora Te Waihora/ECan/Waterways Centre for Freshwater Management to initiate a storm/flood flow-monitoring programme.
8. Approach ECan/Waihora Ellesmere Trust/Waterways Centre for Freshwater Management to establish a regular water quality monitoring review frequency. This could potentially be every five years and include all interested stakeholders.

Chapter Six – Conclusions

All freshwater lakes in New Zealand are currently being impacted by numerous changing pressures of both anthropogenic and climatic origin. The aim of this study was to design a programme to monitor and manage Te Waihora in the most efficient and cost-effective manner within the context of an integrative monitoring programme for Te Waihora as envisaged by Hughey (2015). This thesis includes an assessment of the physical and historical situation of Te Waihora and of current freshwater legislation. The research designs a new integrative water quality monitoring programme to identify Te Waihora water quality state and trends, and considers the ongoing role and integration of current stakeholder monitoring.

Te Waihora and its catchment is a complex, interconnected freshwater system consistent with its identity as an ICOLL. Initial compilation of information on existing monitoring programmes provided an overall review of what is currently being monitored and where. This included both small, localized programmes and catchment-wide programmes and showed where data collection gaps occurred.

A robust, overarching and future-focused water quality monitoring programme for Te Waihora was designed using predetermined criteria to validate the selection of tributaries, sites, parameters and frequency. This integrative water quality monitoring programme proposes monthly monitoring of the six lake and eight tributary sites for all regulatory parameters (NPS-FM [2014] amended 2017, and CLWRP) as well as parameters of specific interest in Te Waihora, such as nutrients and sediment. Additional monitoring is proposed for further specific parameters (emerging contaminants, heavy metals, PAH) at 1 to 5 yearly frequencies. Recommendations to achieve the overarching integrative objectives, for foreseeable future requirements for management and modelling, were made. The “robustness” of all aspects of the monitoring (practical and financial) is acknowledged as essential for longevity.

A comparison of this design with existing stakeholder monitoring was used to show where any gaps or omissions occurred. Recommendations have been made on potential ways to address these gaps, through integration and modification (where applicable) of existing stakeholder monitoring and the creation of new monitoring sites. The current collaborative management of this lake and its catchment, led by Ngāi Tahu and the local authorities (ECan, SDC and CCC), has created a regime where cost-efficiencies can be made by the integration of existing programmes and possible changes or additions. The implementation of this programme can benefit from this approach.

6.1 Limitations of this research

A monitoring programme may be limited in its usefulness for management if all factors influencing its design are not clearly documented. In this case, one such influencing factor is the climate. This research programme included measurements and assessments made from 2015 to 2017. In 2015–2016, the Canterbury region was in the grip of a serious drought, as well as experiencing a steep increase in land use intensification and associated irrigation. One advantage this may have, is to highlight the role of climatic conditions now, and for any future climate change. However, it also emphasises the need for regular programme reviews if the design proves to be inappropriate for wetter seasons. Reviews build some degree of resilience into the monitoring programme itself, but as noted previously, any changes require serious consideration of the break in continuity they cause.

This proposed programme does not include the monitoring of localized improvement initiatives, which require more specific monitoring programmes and could involve citizen science for particular attributes or parameters. Many of the proposed programme parameters are not as relevant to localised improvement initiatives, as they are to overall trend detection. Instead, the proposed programme tributary monitoring sites are chosen to show cumulative results for the whole catchment.

6.2 Recommendations for further research

The following recommendations are made for further research to reduce uncertainties inherent in this proposed programme:

- The validation (as per the recommendations in Chapter 5) of new sites, parameters and frequencies and the inclusion of a new tributary rather than an existing tributary, as well as a new lake site, will require significant further research. This could be carried out by the Waterways Centre for Freshwater Management and/or LU/UC students (as noted).

- Recommendations for some research to establish a valid relationship between turbidity, TSS and clarity (specific to each site) to decrease the cost of testing all three, may be beneficial. It may not however, be prudent for the anticipated future use of data, as one of Te Waihora's major problems is sediment load, and the continued monitoring of TSS (as well as VSS) is strongly recommended.

- The effect of extreme rain events on the areas of Te Waihora that are potentially most impacted by flood sediment loads is a topic to consider, particularly with a view to future change in climate patterns. The contribution of tributary sediment and nutrient loads has had some research (e.g., Kelly et al., 2014; Mitchell, 2012) but no routine monitoring. The recommendation would be to carry out future research for monitoring and flow recorder sites, over a range of flow conditions, to enable accurate load data to be available for management purposes. As noted previously by others, one area where flood sediment and nutrient run-off loads are likely to be inaccurate is Banks Peninsula. Flood flows carry a disproportionately large fraction of both sediment and nutrient load (Elliott & Sorrell, 2002).

- Current research into the effects of the updated opening/closing regime (e.g., the effect on fish spawning or lake flies), sediment, or N and P metabolism within the lake, will all need to be taken account when the monitoring programme is reviewed.

- Water quality monitoring of the effects of localized improvement initiatives would confirm current land management processes and clarify the cost-effectiveness of the initiatives. This monitoring could be planned and initiated by stakeholders such as WET or LU/UC and carried out by local communities.

- Current knowledge of emerging contaminants will dictate their inclusion in the routine monitoring programme. Land use may dictate the contaminants of concern, such as veterinary products, urban wastes or horticultural spraying. This type of research should also be considered in the routine monitoring programme review.

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